GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

2 January 1968

Rome Air Development Center
Procurement Division (EMK)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Monthly Status Report No. 1
Covering the period from 1 December 1967 to 1 January 1968

Gentlemen:

The active interference suppression devices which were developed under Contract No. F30602-67-C-0066 are typically limited to RF input levels of less than 1 milliwatt. Many operational situations, however, involve interfering signal levels of 100 milliwatts and higher. To effectively suppress such high level interference, an increase in the power handling capabilities of the active devices is required. As a first step in the development of devices capable of suppressing high level interference, a preliminary literature search was conducted to ascertain the state-of-the-art power handling capabilities of semiconductor devices operating in the region of 225 to 400 MHz. The published specifications of these transistors would seem to indicate that the desired 2 watt operating level should be obtainable. However, a power output specification of 5 to 10 watts for a transistor does not assure that the device can be employed directly in an active cancellation filter to suppress a high level interfering signal. For cancellation the device must duplicate the undesired signal without adding additional signal components. Therefore, cancellation filters require extremely linear active components. In addition, devices such as the Q multiplier also require linear components to prevent the generation of intermodulation and cross modulation products. To achieve the high operating level with sufficient linearity, the utilization of high power transistors in conjunction with negative feedback and a power sharing mode of operation is under study.

A voltage tuning capability often means that the active devices are simpler to adjust and can be realized in a configuration of reduced size. Since the tuned elements of the devices often operate at high signal levels, a study of the characteristics of voltage variable capacitors in the presence of high RF signal levels is presently being conducted.

On December 18 and 19, project personnel visited RADC to discuss the planned activities for the program. In response to the needs of the sponsor, initial effort is being directed to extending the power handling capability and to expanding the frequency range of the voltage controlled phase shifter developed under the previous program.

The activities during the first month were essentially in conformance with the projected work schedule.

Next month, the study of UHF transistor circuits and techniques for increased power handling capabilities will be continued. The evaluation of voltage variable capacitors at high RF levels will also continue. The expansion of the operating range of the voltage controlled phase shifter will be initiated.

To provide continuity with the previous work, the following individuals are presently assigned to the project:

D. W. Robertson	Senior Research Engineer
H. W. Denny	Research Engineer
R. A. Byers	Assistant Research Engineer
C. R. Driskell	" " "
C. S. Wilson	" " "

The following engineering man-hours were directed to the project effort during this reporting period:

Research Engineer	38
Assistant Research Engineers	264

Respectfully submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

February 2, 1968

Rome Air Development Center
Procurement Division (EMK)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Monthly Status Report No. 2
Covering the period from 1 January 1968 to 1 February 1968

Gentlemen:

Primary emphasis during this month was directed toward a study of the linearity characteristics of transistor amplifiers and varactor tuned filters as a function of the RF drive level. A series of tests on a 2N4259 transistor amplifier showed that, although a range of emitter currents exist at which the amplifier exhibits reduced harmonic generation, the second and third harmonics are, in general, only 30 to 40 dB below the output level of the fundamental. A similar series of tests on a 2N3866, a transistor with a 5 watt collector dissipation, revealed significantly improved linearity characteristics. Above 16 ma emitter current, the second harmonic generated by the 2N3866 is 40 dB lower than the output power level of the fundamental and the third harmonic is greater than 55 dB below the fundamental. In addition, the harmonic products continue to decrease as the emitter current increases. Further tests are planned with this transistor in higher output power amplifier configurations.

The harmonic generation properties of a varactor tuned filter were performed using a 1N5139 diode. These tests showed that third harmonic generation (which is a measure of the third order intermodulation properties of the device) was relatively insignificant in the filter. The second harmonic generation in the filter was typically 30 dB below the power level of the fundamental at RF levels near 0.3 volt. However, second harmonic generation can be minimized by employing two diodes in a back-to-back configuration. The results indicate that varactor tuned resonators should perform well at RF levels in excess of 0 dBm.

Other activities during the month included the procurement of materials and supplies for the construction of printed circuits and strip transmission line components.

The activities during this month were essentially in conformance with the projected work schedule.

Next month, the study of UHF transistor circuits and techniques for increased power handling capabilities will continue. Strip transmission line resonators will be constructed and evaluated for use in the voltage controlled phase shifter as well as for other active filter applications.

No significant personnel changes occurred during January.

The following engineering man hours were directed to the project effort during this month:

Principle Research Engineer	26
Research Engineer	176
Assistant Research Engineer	411

Respectifully submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

4 March 1968

Rome Air Development Center
Procurement Division (EMK)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Monthly Status Report No. 3
Covering the period from 1 February 1968 to 1 March 1968

Gentlemen:

During February, the development of a broadband amplifier configuration was emphasized. A common emitter amplifier incorporating a 2N3866 transistor was developed that exhibited 6 ±0.5 dB gain from 50 MHz to 400 MHz. The flat gain characteristic was obtained through the application of negative feedback and wideband impedance matching. A significant feature of the amplifier's construction is the utilization of printed circuit techniques. Through the use of such techniques, the dependence of the gain characteristics on the particular placement of components was reduced. Consequently, duplication of the wideband gain characteristics should be relatively easy. This feature is necessary for effective power sharing because several identical amplifiers must be employed. Future tests on the common emitter amplifier will include a comparison of its linearity characteristics with those of the common base amplifier.

The construction of strip line resonators has been delayed pending delivery of the strip transmission line materials.

The development of an improved voltage controlled phase shifter has been slowed by difficulties encountered in the amplifier construction. The achievement of the desired power handling level requires the use of transistors which have relatively low isolation between the collector and base. Because of the interaction between the input and output which results from this low isolation, the very low gain ripple necessary for good phase shifter performance is not easily realized. It is anticipated that these difficulties will be overcome shortly and the phase shifter development will proceed without delay.

The activities during this month were essentially in conformance in with the projected work schedule.

Next month, the study of UHF transistor circuits and techniques for increased power handling capabilities will continue. The strip line material should be delivered next month and the development of directional couplers, resonators, and other printed circuit devices will be resumed.

No significant personnel changes occurred during February.

The following engineering man hours were directed to the project effort this month:

Principal Research Engineer	26
Research Engineer	176
Assistant Research Engineer	397

Respectfully submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

2 April 1968

A-1058

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 4
Covering the period from 1 March to 1 April 1968

Gentlemen:

The investigation of transistor amplifiers was continued during March. Additional configurations utilizing 2N3866 transistors and one configuration using a 2N5090 were constructed and evaluated. Tests were conducted to determine the relative linearity characteristics of the emitter degenerative and grounded base amplifiers. The emitter degenerative amplifiers exhibited gains of 5 to 7 dB. At an input level of +10 dBm, the second harmonic level generated in the amplifiers was typically 40 dB below the fundamental output level and the third harmonic level was 50 dB or more below the fundamental. The grounded base amplifier exhibited a gain of about 6 dB. However, the second harmonic level was only 10 dB down and the third harmonic level was only 25 dB down from the fundamental output level. The investigation of additional transistors in the emitter degenerative amplifier configuration is planned.

On March 25 and 26, H. W. Denny visited Mr. George Long and Mr. Wayne Woodward at RADC for the purpose of reviewing past efforts and discussing future goals. As a result of this meeting, emphasis will be placed on the development of an improved UHF Q multiplier. Effort will be directed toward improving the noise figure, the bandwidth, and the power handling characteristics of the device originally developed under Contract F30602-67-C-0066.

A wideband voltage controlled phase shifter with higher power handling capabilities is essential to the improved performance of the Q multiplier. By using two of the emitter degenerative amplifiers, satisfactory phase shifter performance was achieved over a 100 MHz bandwidth. Minor tuning adjustments are necessary to extend the operating range to cover the entire 225 to 400 MHz region.

The strip transmission line materials have been delivered and wideband directional couplers are being constructed. The investigation of strip line resonators will be initiated next month.

The activities during this month were essentially in conformance with the projected work schedule.

Next month, the study of UHF transistor circuits and techniques for increased power handling capabilities will continue.

The following engineering man hours were directed to the project effort this month.

Principal Research Engineer	18
Research Engineer	176
Assistant Research Engineer	374

Respectfully submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

1 May 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 5
Covering the period from 1 April to 1 May 1968

Gentlemen:

The high power, wideband transistor amplifier development program during April consisted of the construction and evaluation of several additional configurations. Using such transistors as the 2N3375 and the 2N5090, the desired wideband performance was readily achieved. Comparative tests of the relative linearity charactertistics of these two transistors showed that the 2N3375 amplifier exhibited less harmonic generation than the 2N5090. Typically, the third harmonic generated by the 2N3375 amplifier was greater than 60 dB below the fundamental output level at power outputs up to + 10 dBm.

To achieve additional reduction in the second harmonic level, an amplifier configuration was constructed employing two 2N3375 stages operating in parallel. Although the individual stages operated as desired, they did not produce the desired gain when operated together. Although the specific reason for the reduced gain has not been definitely established, it is believed that the widely varying input impedance of the two stages prevents the proper operation of the input hybrid. In addition, spot checks of the relative phase shifts through the two stages indicated that large differences exist. For proper power addition at the output, the output signals of the two stages must be in phase. Additional configurations are presently under construction which, hopefully, will be more closely matched in phase characteristics. The development of a network for matching the input of the amplifier stages to the input hybrid will be investigated next month.

High directivity directional couplers were constructed using strip line techniques. The couplers exhibited 10 dB nominal coupling with a nominal directivity of 35 dB. These couplers have proven extremely useful in the measurement of the terminal impedances of the broadband amplifiers.

The activities during this month were essentially in conformance with the projected work schedule.

Next month, the study of VHF transistor circuits and techniques for increased power capabilities will continue. The primary emphasis will be placed on the development of a power sharing configuration of two parallel stages operating in either push-pull or push-push.

The following engineering man hours were directed to the project effort this month.

Principal Research Engineer	18
Research Engineer	158
Assistant Research Engineer	317

Respectfully submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION
225 North Avenue, Northwest · Atlanta, Georgia 30332

10 June 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 6
Covering the Period from 1 May to 1 June 1968

Gentlemen:

The investigation of high power transistor amplifiers continued during May. The difficulties reported last month with the two transistor stages in parallel were never fully resolved. Further experimentation failed to produce the desired gain characteristics. Because of the interaction between stages, tuning to obtain the necessary phase match at the input and output of the two stages for signal addition was very difficult. The desired flat gain response was more readily obtained with an amplifier constructed in a strip transmission line configuration. The same strip line technique was used in the construction of an amplifier having two stages in parallel. The reduced interaction between stages permitted a flat gain characteristic for the parallel stages to be achieved. The two stages were operated in both push-pull and push-push modes. The level of second harmonic generation for the push-pull mode was typically 10 dB below the level of generation for the push-push mode. In the push-pull mode, the third harmonic generation of this amplifier was typically 55 dB below the fundamental at a power output of +16 dBm and typically 40 dB below the fundamental at +26 dBm output level. In view of the promising performance exhibited by this amplifier, several more will be constructed for operation in parallel to achieve the high level output with low distortion.

The results of a preliminary investigation of distributed amplification techniques with both field effect and conventional transistors were not encouraging. Nor was significant success achieved with field effect transistor amplifiers in either narrowband or broadband configurations. Some recent experiments have indicated that a wideband amplifier, capable of producing output levels in excess of +10 dBm, can be achieved with an emitter follower configuration. This configuration will be investigated further next month.

The investigation of compact, voltage tuned resonators has been resumed. Further studies of these devices are planned for next month.

The activities during this month were essentially in conformance with the projected work schedule.

Next month, the study of UHF transistor circuits and techniques for increased power capabilities will continue. In addition to the previously mentioned activities which are planned, the construction of the high power transistor amplifier will be initiated next month.

The following engineering man hours were directed to the project effort this month:

Principal Research Engineer	16
Research Engineer	120
Assistant Research Engineer	378

Respectfully submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

2 July 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 7
Covering the period from 1 June to 1 July 1968

Gentlemen:

The high power transistor amplifier development program continued this month with the construction of another strip line version of the parallel stage amplifier. Two of these amplifiers were operated in a push-pull mode through the use of 180 degree hybrid networks. In this way, the available output power was increased while the level of harmonic generation was decreased. For example, at a power output level of + 27 dBm, the second harmonic was typically 40 dB and the third harmonic typically 55 dB below the fundamental. With these amplifiers in a feed forward cancellation system, 50 dB suppression of a + 27 dBm AM signal was obtained. At an input level of 0 dBm, approximately 60 dB suppression of an AM signal and more than 70 dB suppression of a CW signal could be obtained with the same system. Because of this encouraging performance, the final model of the amplifier is under construction.

The efforts to develop a voltage variable phase shifter to cover the 200 to 400 MHz have been largely unsuccessful. Because of the difficulties in cascading high power rf transistors to achieve an extremely flat gain characteristic, the desired amplitude-invariant phase shifter has not been achieved. However, an effective phase shifter has been realized through other techniques. This phase shifter meets the needs of anticipated systems.

A two port active network was developed which performs as a reflection amplifier. This device was incorporated into a Q multiplier which exhibited a sensitivity of approximately -100 dBm with an effective Q in excess of 10,000. Its power handling capability was in the neighborhood of + 7 dBm.

The activities during this month were essentially in conformance with the projected work schedule.

Next month, the study of UHF transistor circuits and techniques for increased power handling capabilities will continue. The development of other components such as directional couplers, hybrids, and resonators will continue to be emphasized.

The following engineering man hours were directed to the project effort this month:

Principal Research Engineer	9
Research Engineer	148
Assistant Research Engineer	348

Respectfully submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

6 August 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 8
This report period covers from 1 July to 1 August 1968.

Gentlemen:

The activities of the previous months have been largely directed to the development of amplifiers, couplers and other components needed for the construction of an advanced Q multiplier. During this past month many of these components were incorporated into various Q multiplier configurations for comparative studies.

Configurations employing multiple feedback loops and cascaded sections of single loop feedback sections were evaluated. High, stable Q's were realized with a two-loop Q multiplier configuration. The effective Q of a small coaxial cavity was multiplied from 160 to 4000 in two steps. The 30 dB bandwidth of the two loop configuration was 3 MHz compared to 7.5 MHz for a single loop multiplier. This narrowing of the 30 dB bandwidth indicates that improved skirt selectivity is also obtained from a multiple loop configuration.

Cascaded stages of multiplied Q were also evaluated. This filter configuration simply incorporates two or more high Q resonators in series. Through the use of Q multiplication techniques, narrow band responses with very steep skirt selectivities were obtained. Figure 1 compares the responses of two and three stage cascaded resonators with the responses of conventional high Q coaxial cavities. These curves show that the cascaded stages exhibit greatly improved skirt selectivities. These four filters were evaluated for their effectiveness in reducing interference from a closely spaced signal in an AN/APR-4 receiver. The preselector of the AN/APR-4 exhibited 30 dB rejection to a signal spaced 2 MHz from the tuned frequency at 300 MHz. The single tuned cavity increased the rejection to 52 dB and the Model 56C-2 multicoupler increased the rejection to 70 dB. The three stage Q multiplier configuration increased the rejection of receiver to this interfering signal to 92 dB.

The techniques for the development of voltage tuned resonators covering the range from 200 to 400 MHz were examined in detail during July. Both quarter-wave coaxial resonators and helical resonators were examined. The desired tuning range was obtained with a 1N5139A varactor incorporated as a series tuning element in a coaxial resonator. The insertion loss, however, was 6 dB or greater across the range and the loaded Q was typically 100. In a parallel tuned coaxial cavity, an octave range was not obtained and the insertion loss was excessive. Loaded Q's ranging from 40 to 100 were typical for this configuration.

A parallel tuned helical resonator also exhibited an excessive insertion loss and the tuning range was less than an octave. These preliminary tests did not seek to optimize the center conductor configuration or the coupling probe position. It is anticipated that the performance of the helical resonator can be improved by optimizing these factors.

In each of the configurations tested, the low Q's observed could not be explained in terms of either the cavity Q or in terms of the varactor Q. Further development of coupling techniques is expected to increase the Q and decrease the insertion loss.

The activities during this months were essentially in conformance with the projected work schedule.

Next month, the development of advanced Q multiplier techniques will be emphasized to include the initiation of construction of a feasibility model of a multi-stage bandpass filter using these techniques.

The study of voltage tuning techniques will continue. The development of other components required for the Q multiplier will continue.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal Research Engineer	18
Research Engineer	169
Assistant Research Engineer	537

Respectfully Submitted,

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

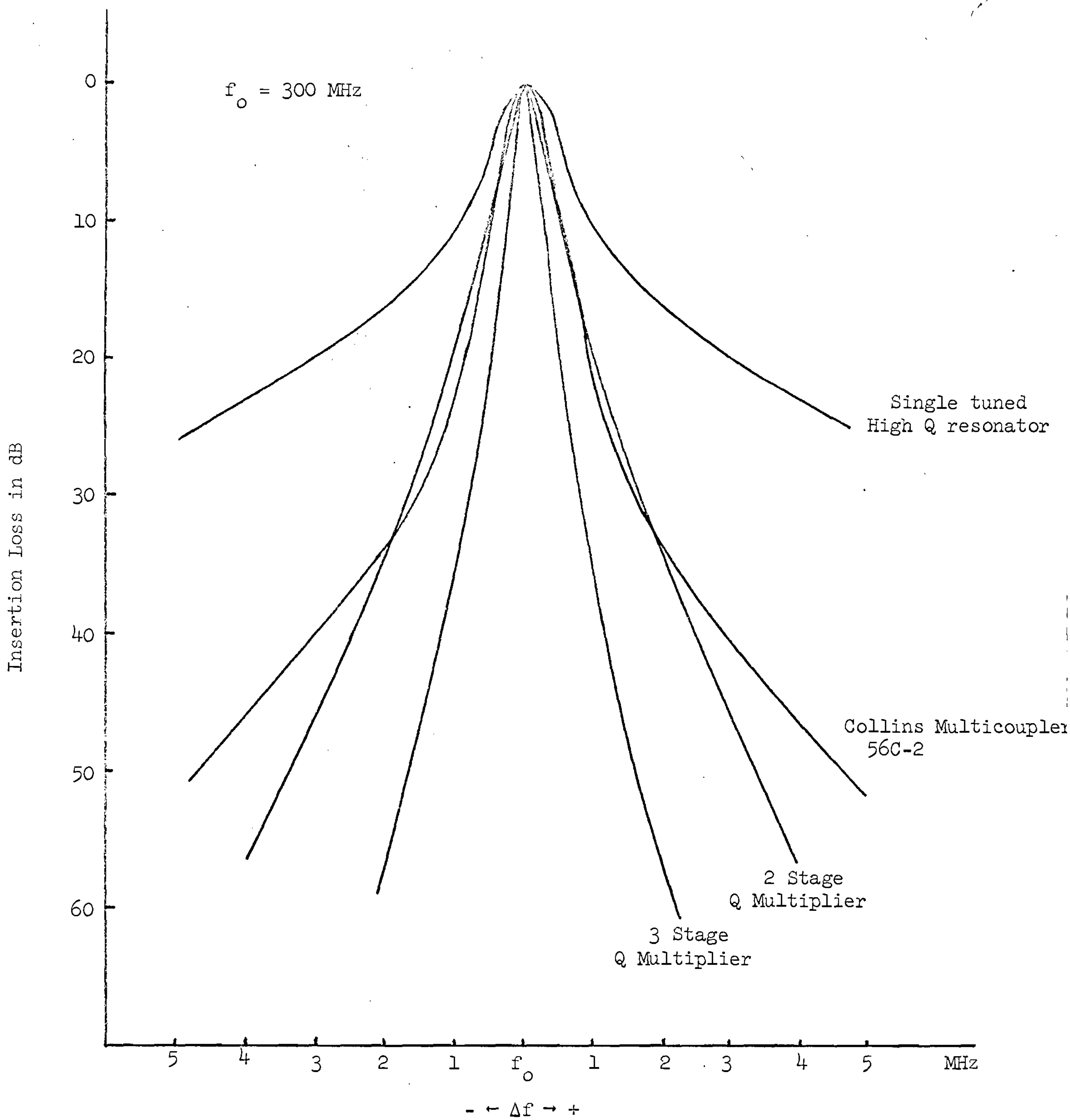

Figure 1. Bandpass Characteristics of UHF Preselectors.

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

5 September 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 9
This report covers from 1 August to 1 September 1968.

Gentlemen:

In addition to the previously discussed Q multiplication technique employing feedback loops, other techniques of Q multiplication have been investigated. A well known technique which is successfully employed at low frequencies is the application of a negative resistance to a resonant circuit. This negative resistance reduces the circuit losses and hence raises the Q. An emitter follower configuration was successfully employed to produce a stable negative resistance over a wide frequency range. By terminating a 50 ohm coaxial cavity with this negative resistance, the effective Q of the cavity was doubled. Effective Q's approaching the unloaded Q of the cavity were obtained by appropriate adjustment of the coupling loops. The net insertion loss through the cavity and emitter follower was 0 ± 1 dB from 225 to 400 MHz. Third order intermodulation components generated by two 0 dBm signals with 200 kHz spacing were greater than 50 dB down.

The 60 dB bandwidth of three cascaded stages of the cavity-emitter-follower combination is calculated to be 4.2 MHz. This bandwidth is less than half the 9 MHz 60 dB bandwidth exhibited by the Collins model 156C-2 multicoupler.

Effective Q's from 2200 to 4000 were obtained with an emitter follower constructed inside the cavity. By adjusting the base-to-collector voltage, a resonant circuit exhibiting 100 kHz bandwidth (3 dB) with 11 dB gain could be achieved from 225 to 400 MHz.

Coaxial cavity resonators to be used in the cascaded Q multiplier configuration are presently being fabricated.

The investigation of voltage tuned resonator techniques was continued with the construction of two helical resonators — one with a two-inch diameter shield and the other with a one-inch diameter shield. By reducing the number of turns in the center helix and adding a variable capacitor, both resonators could be tuned over the 225 to 400 MHz range. However, these modifications reduced the Q of the resonators considerably. The Q was much lower when using a varator for tuning than when using a ceramic trimmer capacitor of a similar capacity range.

The design and circuit construction phase of the UHF AM Cancellation Filter has been completed and current efforts are being directed toward final packaging details. The rough draft of an operating and service manual has been essentially completed. This manual is to be supplied with the instrument and includes system specifications, system capabilities, and detailed operating procedures.

The activities during this month were essentially in conformance with projected work schedule.

Next month, the investigation of voltage tuned resonators will continue. The construction of the multi-stage bandpass filter will be accelerated. The AM cancellation filter will be completed.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal Research Engineers	18
Research Engineers	172
Assistant Research Engineers	502

Respectfully submitted,

H. W. Denny
Project Director, Project A-1058

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

3 October 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 10
This report covers from 1 September to 1 October 1968.

Gentlemen:

The UHF AM Cancellation Filter is almost complete. The gear mechanisms to tune the cancellation and first local oscillators and to drive the frequency readouts were assembled during the past month. The circuit diagrams have been completed and are presently being drafted. The remaining activities include (1) the painting and labeling of the front panel, (2) assembly of the instruction manual, and (3) final checkout of the filter.

In view of the promising performance of an emitter follower configuration as a Q multiplier further study of the technique was performed. With the emitter follower configuration followed by a buffer amplifier, effective Q multiplication of a coaxial cavity was obtained over a wide frequency range. Effective Q's in excess of 1000 were achieved from 220 MHz to 400 MHz with small coaxial cavities. For this selectivity, the amplifiers can handle signal levels of 0 dBm with the third harmonic greater than 40 dB down. An increase in the power handling capability to + 10 dBm can be obtained at the expense of selectivity by providing a 6 dB pad between the emitter follower and buffer amplifier.

The construction of the cavity resonators for the cascaded Q multiplier has been completed. The design of the mounting fixtures and tuning mechanisms for the cavities is presently being performed. Provisions for a voltage controlled frequency vernier are being included for fine tuning of the resonators.

Efforts continued to be directed toward the development of high Q, voltage tuned resonators during September. By correct positioning of the input and output coupling loops, a flat insertion loss characteristic was achieved over the frequency range of 225 to 400 MHz. Effective Q's in the neighborhood of 300 and above were obtained by terminating the varactor tuned cavity with a negative resistance as realized with an emitter follower amplifier. Experimental evidence indicates that varactor losses have restricted the Q's of the resonators. Some high Q varactors have been obtained but have not been evaluated. Further tests are planned to see if higher resonator Q's can be obtained with the low loss varactors.

The activities during this month were essentially in conformance with the projected work schedule.

The planned activities for next month include the completion of the final packaging details of the AM Cancellation Filter, the continued development of the cascaded Q multiplier filter and futher study of voltage tuned resonator techniques.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal Research Engineers	17
Research Engineers	162
Assistant Research Engineers	503

Respectfully submitted:

H. W. Denny
Project Director, Project A-1058

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

1 November 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 11
This report covers from 1 October to 1 November 1968.

Gentlemen:

Construction details have been completed on the UHF AM Cancellation Filter. The developmental model will be delivered as soon as the instruction and maintenance manual is printed. It is anticipated that delivery will be possible during November.

The mechanical design of a cascaded Q multiplier has been completed. Shop construction of the mechanical portions of the filter are approximately 50 per cent complete. The completion of the cavity tuning mechanism may be delayed due to slow delivery of special gears. Further electronic circuitry construction must be delayed until the mechanical portion of the filter is completed.

The activities during this month were essentially in conformance with the projected work schedule.

The planned activities for next month include continued development of the cascaded Q multiplier and further developmental work on a reduced-size version of the positive feedback Q multiplier.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal Research Engineer	18
Research Engineer	168
Assistant Research Engineer	302

Respectfully submitted:

H. W. Denny
Project Director, Project A-1058

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

4 December 1968

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 12
This report covers the period from 1 November to 1 December 1968.

Gentlemen:

The UHF AM Cancellation Filter was shipped to RADC in November. A draft copy of the instruction and maintenance manual was forwarded with the equipment. Final copies will be forwarded when they are completed. Project personnel are planning a trip to RADC early in December to demonstrate the operation of the filter.

Further development of the cascaded Q multiplier has been slowed due to continued delays in the delivery of some special gears. Completetion by the end of December of the Q multiplier had been planned, but because of the delays encountered in the delivery of the mechanical components, it does not appear likely that this goal can be realized.

Developmental work on a reduced-size version of the positive feedback Q multiplier has continued. Several attempts have been made previously to realize a voltage controlled phase shifter that operated over the entire 225-400 MHz band but satisfactory performance was not obtained. Concentrated efforts are now being applied to the development of this device because of its importance to the positive feedback Q multiplier.

The activities during this month were essentially in conformance with the projected work schedule.

The planned activities for remaining period includes continued development of the cascaded Q multiplier and developmental work on the positive feedback Q multiplier.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal Research Engineer	17
Research Engineers	132
Assistant Research Engineers	313

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

3 January 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffis Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 13
This report covers the period from 1 December 1968 to 1 January 1969.

Gentlemen:

Project personnel visited RADC on December 5 and 6 for the purpose of demonstrating the operational characteristics of the UHF AM Cancellation Filter.

The delivery of some special gears early in December permitted the completion of the mechanical portions of the cascaded Q Multiplier. The development of the electronic circuitry and resonant structures was continued and is being actively pursued.

Significant progress has been made toward the development of a phase shifter for use in the reduced-size version of the positive feedback Q Multiplier. Satisfactory results have been achieved in the design of both broadband and tunable amplifiers. A broadband amplifier was constructed which provides a gain $14 \pm 1/4$ dB over the frequency range of interest. Current design efforts of an amplifier for the tuned channel make use of a common emitter amplifier with the collector tuned with an air variable capacitor ganged with a variable inductor. The amplifier exhibits a gain of 14 dB at 200 MHz which decreases to 11.7 dB at 400 MHz. The smooth roll-off minimizes the difficulty in gain compensation in the broadband channel.

An investigation will be made into the use of a varactor with a large ΔV to replace the present mechanical tuning arrangement. It is hoped that a varactor-tuned amplifier can be designed that will exhibit a smooth gain vs frequency characteristic to facilitate the required channel matching.

The activities during this month were essentially in conformance with the projected work schedule.

The planned activities for next month includes increased emphasis on the development of the cascaded Q Multiplier and continued development of the positive feedback Q Multiplier.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal Research Engineer	9
Research Engineer	118
Assistant Research Engineer	208

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

7 February 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 14
This report covers the period from 1 January to 1 February 1969.

Gentlemen:

Early in the month, experimental evaluation of the cascaded Q multiplier was resumed. The tests revealed that the amplifier which had been constructed previously for use in the filter was not operating in a negative resistance mode. Although high effective Q's were obtained, the filter's response characteristics were primarily determined by the cavity coupling. The amplifier was only supplying the gain necessary to overcome the insertion loss of the cavity resonator. Since the cavity precedes the amplifier, the insertion loss directly degrades the noise figure of the filter. Consequently, an alternate approach was required.

A two terminal active network which operated as a reflection amplifier was briefly described in Contract Status Report No. 7. A network having similar characteristics was refined and used as a negative resistance to enhance the Q of the cavity resonator. In addition, the insertion loss of the cavity was significantly reduced with net gain produced over much of the 225 to 400 MHz range. The stability of the reflection amplifier is particularly dependent on the value of the terminating impedance. Therefore, considerable experimentation was necessary to determine the correct cavity coupling loop configuration. In addition, a buffer amplifier was required to isolate the reflection amplifier from following stages. The response characteristics of the cavity, reflection amplifier and buffer amplifier exhibit typical Q's from 600 to 1000 which represent a multiplication of the cavity's Q of from approximately 1.1 to greater than 3. The net gain through the system varies from 10 dB to 23 dB. The noise and gain characteristics of the combination permit a 6 dB (S + N)/N ratio to be obtained with signal levels ranging from -92 dBm at 225 MHz to -106 dBm at 400 MHz.

The amplifiers for the remainder of the system are completed. Appropriate coupling loops for the remaining two cavities have been tentatively determined. These cavity resonators will be completed and the entire three stage system evaluated early next month.

Continuing efforts toward the development of a 225 to 400 MHz electronically controlled phase shifter have been directed primarily to achieving varactor control of the tuned channel and obtaining the necessary amplitude and phase tracking between the tuned and broadband channels.

A varactor controlled tuned channel amplifier was designed and constructed which tuned over the required frequency range. Unfortunately, the input signal level was limited to -20 dBm at the low end of the frequency range. The varactor bias voltage must vary from approximately zero volts to the maximum rated reverse bias to tune over the full frequency range. Therefore, at frequencies near 225 MHz the reverse bias voltage is low and moderate RF signal levels drive the varactor into conduction. Because of this problem, it may be necessary to cover the frequency range in two bands. Current efforts are being devoted to the design of a "high band" phase shifter which will cover the frequency range from 250 to 400 MHz.

Amplitude tracking between the tuned channel and broadband channel was achieved, but some problems have been encountered in acquiring proper phase tracking between the two channels. Initial tests have shown that a constant phase difference exists between the two channels which is not easily corrected with a simple "fix" such as adding a constant time delay to one of the channels. Continuing efforts will be directed toward eliminating this phase offset between channels and to the further development of the high band phase shifter.

The activities during this month were essentially in accordance with the projected work schedule.

The planned activities for next month include the assembly and evaluation of the cascaded Q multiplier filter and continued emphasis on the the development of the voltage controlled phase shifter for use in a feedback Q multiplier.

The following level of engineering effort was devoted to the project this month:

Principal and Senior Research Engineers	84
Research Engineers	172
Assistant Research Engineers	144

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

HWD:irl

GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

3 April 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss AFB, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 16
This report covers the period from 1 March to 1 April 1969

Gentlemen:

Early in the month, project personnel visited RADC to review the activities of the project to date and to coordinate the activities to be conducted under the project extension.

The developmental activities were primarily directed toward final engineering efforts on the cascaded Q multiplier filter. The incorporation of a wideband, low noise, high gain amplifier into the system provided a significant increase in tangential sensitivity particularly in the lower frequency portions of the operating range. The arrangement of the cavities and amplifiers was modified to take advantage of the noise properties of the high gain amplifier. With an Avantek AP-20 amplifier in the modified arrangement, a tangential sensitivity of -97 dBm is typical at 225 MHz. From 260 MHz to 400 MHz, the tangential sensitivity is better than -100 dBm.

The cavity tuning mechanism is complete. Additional machine work was required to reduce backlash to within acceptable limits. The remaining machine work includes a front panel, dust cover and final assembly and alignment.

Electronically stepped attenuators have been developed for use in the system.

A preliminary study of possible approaches to a phase shiftless, voltage-controlled attenuator was performed. A study of published data on current PIN diodes indicates that these devices can be characterized by a voltage variable resistance and a fixed capacitance. Mathematical analysis indicates that this capacitance can be balanced out to provide a variable resistance function. Several circuit configurations have been examined and the more promising ones are under construction for evaluation.

A detailed study of the voltage controlled phase shifter was made to determine the cause of the phase offset between channels as reported in Status Report No. 14. This study indicated that this phase offset can be reduced by isolating the tuned circuit with attenuators from the amplifier stages which precede and follow it. In addition, alternative phase shifter techniques are currently under examination.

The activities for next month will emphasize the development of the electronically controlled attenuator and phase shifter.

The activities during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal & Senior Research Engineers . . .	106
Research Engineers	176
Assistant Research Engineer	176

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

3 March 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 15
This report covers the period from 1 February to 1 March 1969.

Gentlemen:

The activities this month were primarily directed to the development of the cascaded Q multiplier filter configuration. The positions of the coupling loops for the second and third cavities were established. With all three cavities and the amplifiers assembled into a final configuration, a net Q greater than 1250 was obtained over the range from 225 to 400 MHz. The gain of the filter varied from -5 dB at 225 MHz to +20 dB at 400 MHz. It's 50 dB bandwidth of 2.9 MHz at 300 MHz is less than one-third that of the model 156C-2 multicoupler.

The addition of the second and third cavities degraded the noise figure of the filter at the low end of the operating range. The gain of the negative resistance amplifier and the first buffer amplifier is not sufficient to overcome the insertion loss of the last two cavities at the lower frequencies. Efforts are currently underway to develop an improved first buffer amplifier which will supply the needed gain.

Once the three cavities were assembled, further refinements in the tuning mechanism were found to be necessary. Appropriate hardware items have been ordered to make the needed adjustments.

The activities during this month were essentially in accordance with the projected work schedule.

The planned activities for next month include continued development of the cascaded Q multiplier with emphasis placed on the improvement of the gain of the buffer amplifiers in the 225-300 MHz region and the refinement of the cavity tuning mechanism. In addition, the development of the voltage controlled phase shifter will be accelerated.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal and Senior Research Engineers	97
Research Engineers	162
Assistant Research Engineer	10

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

5 May 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 17
This report covers the period from
1 April to 1 May 1969

Gentlemen:

Final assembly and alignment of the cascaded Q multiplier was performed this month. Evaluation tests have been run and the final unit is now being prepared for shipment to the Air Force.

The principle activities this month have been directed to the development of the electronically controlled attenuator and phase shifter. A model of an experimental attenuator was constructed. The model consists of two unbalanced Pi networks of PIN diodes. The two attenuator networks are fed by out of phase sources and the outputs of the networks are summed. Attenuation is provided by both (1) attenuation through the networks and (2) outphasing. Cancellation of the imaginary components of the two output components minimizes the phase shift of the resultant.

With the present model, greater than 70 dB attenuation has been achieved with approximately 30 degrees phase shift. A biasing network for the PIN diodes is presently being constructed which is expected to reduce further the output phase shift.

A working model of the broadband phase shifter has been designed and constructed. This model exhibits an amplitude variation of only ±0.75 dB over the frequency range of 250-400 MHz. A summary of the operating characteristics of this phase shifter follows:

Frequency (MHz)	Δ Gain (dB)	θ_{max} (deg.)	Insertion Gain (dB)
250	±0.40	353	2.5
275	±0.30	353	1.3
300	±0.55	352	1.1
325	±0.75	351	1.1
350	±0.70	350	1.7
375	±0.50	346	2.5
400	±0.75	337	4.5

Full coverage of the frequency range of 225-400 MHz is primarily restricted by the varactor diode. To tune over this frequency range requires a capacitance variation of approximately 4:1. Although this capacitance ratio can be achieved, to do so requires that the control bias be reduced to very low values. At low bias, the Q of the varactor decreases significantly, which causes the gain of the tuned amplifier to drop. In addition, under low bias conditions the RF signal can drive the varactor into forward conduction which eliminates the capacitance nature of the diode. The power handling capability of the phase shifter is presently limited to about -15 dBm by the small signal transistors which are being used and by the RF voltage swing which can be tolerated by the varactor at low bias voltages.

The activities for next month will continue to emphasize the development of the electronically controlled attenuator and phase shifter.

The activities during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal and Senior Research Engineers	88
Research Engineer	146
Assistant Research Engineer	167

Respectfully submitted:

Hugh W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

4 June 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss AFB, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 18
This Report covers the period from 1 May to 1 June 1969.

Gentlemen:

The cascaded Q multiplier filter was shipped to the Air Force this month. On 22 May, project personnel visited RADC to demonstrate the operation of the filter. In addition, an extensive review of the progress on the development of the electronically controlled attenuator and phase shifter was conducted.

The development of the attenuator and phase shifter has been stressed this month. Preliminary tests have verified the feasibility of balancing out the reactance component of a PIN diode to achieve variable attenuation with very little phase shift. The attenuator network shown in Figure 1 provides up to 40 dB attenuation with less than 7 degrees maximum phase variation as illustrated by Figure 2. Although the initial network exhibits 2.5 dB insertion loss, it is expected that the final version will have less than 1 dB insertion loss. The terminal impedance is well matched with a VSWR of less than 2:1 over the 225 to 400 MHz range. In view of the promising results of the technique, the design of a stripline attenuator consisting of two of these networks in series is presently underway.

The directional couplers should exhibit flat coupling with frequency to assure broadband operation. Multisection couplers may be required to minimize coupling variations across the frequency band. The use of high dielectric constant stripline material is being considered to minimize the size of the attenuator.

To overcome the power handling limitations of the present voltage controlled phase shifter, techniques which employ PIN diodes to vary the amplitudes of quadrature components of the RF signal are being investigated. The technique under primary consideration divides the RF signal into equal components in quadrature phase. By varying the amplitudes of these two components in a specified manner, the phase of the resultant vector can be varied over a full 360 degrees.

Both commercial and in-house balanced mixers using PIN diodes as the active elements have been evaluated as amplitude controllers of the quadrature components. Thus far, the in-house configurations have exhibited the more desirable characteristics. Before the technique can be implemented it will be necessary to: (1) reduce the phase shift which accompanies the amplitude change through the balanced mixers, and (2) significantly reduce the insertion loss now exhibited by the mixers.

The activities for next month will continue to emphasize the development of the electronically controlled attenuator and phase shifter.

The activites during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month.

Classification	Hours
Principal & Senior Research Engineer	53
Research Engineer	123
Assistant Research Engineer	106

Respectfully submitted:

Hugh W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

HWD/irl

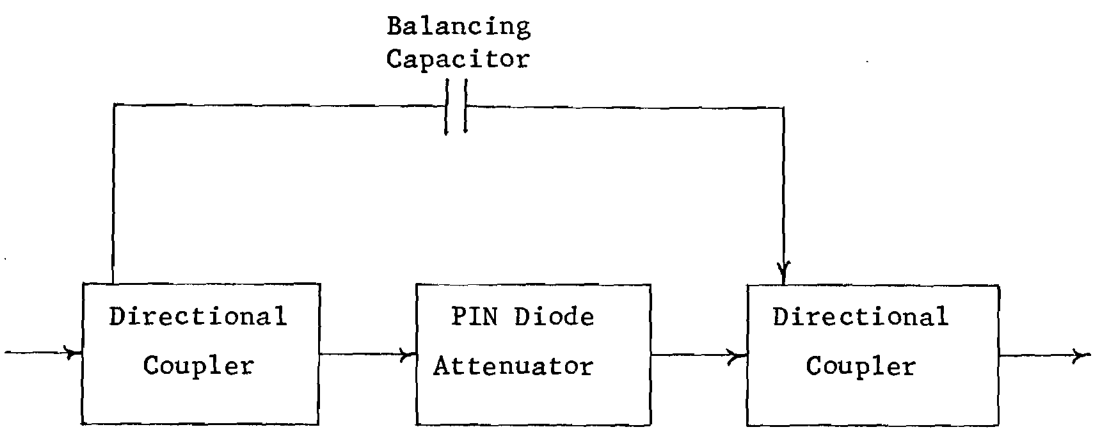

Figure 1. Voltage controlled attenuator network.

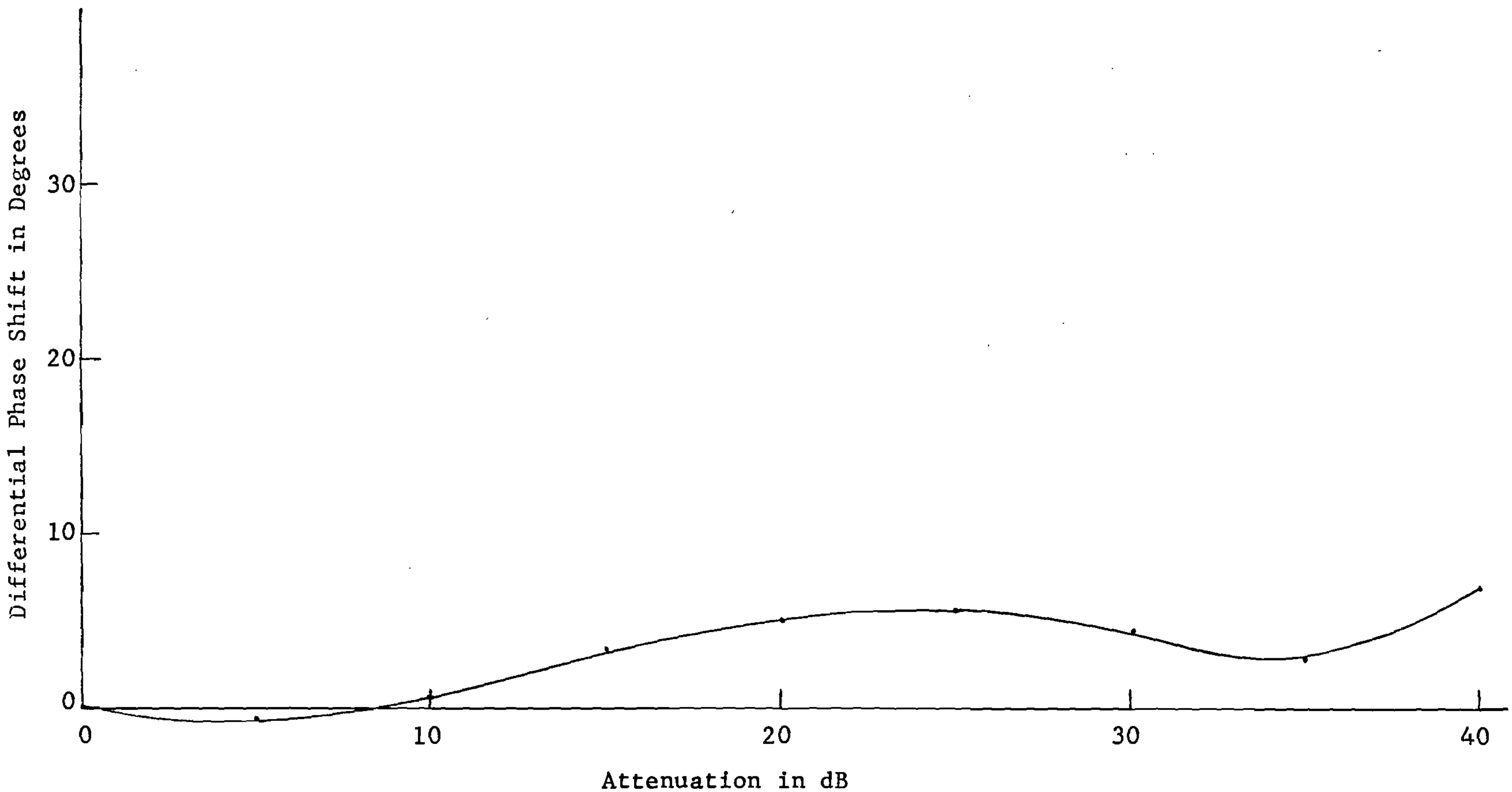

Figure 2. Phase shift characteristics of voltage controlled attenuator.

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30 June 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 19
This report covers the period from 1 June to 1 July 1969.

Gentlemen:

The activites this month were directed to the development of an electronically controlled attenuator and phase shifter. A stripline version of the attenuator network reported last month was constructed. The two directional couplers were constructed in a sandwich-type of balanced line while the connecting lines containing the attenuator and balancing capacitor were realized in a microstrip configuration.

The integrated network exhibited an average insertion loss of 1.7 dB across the 225-400 MHz band. The maximum attenuation was approximately 30 dB in comparison to 40 dB attenuation as obtained with the discrete component network. This degradation is probably due to one or two primary contributors. One, the level of the cancellation signal may not have been set precisely to the correct level. Two, excessive coupling may exist between the microstrip lines on each side of the diode attenuator. The use of high dielectric constant stripline material is expected to significantly reduce this coupling.

Figure 1 shows the maximum phase shift between minimum to maximum attenuation as a function of frequency. Although the initial design center frequency was 300 MHz, the center frequency of the network is at 260 MHz. Extrapolation of the curves indicates that the operating range of this network is 200 to 300 MHz. This curve indicates (1) the directional couplers need to be reduced in length to raise the center frequency to 300 MHz, and (2) multisection couplers are necessary to increase the operating bandwidth to cover the 225-400 MHz band.

The continuing effort on the development of a voltage controlled phase shifter is directed toward the use of balanced modulators with quadrature couplers to generate the desired rotating vector. This technique, as was discussed in the previous status report, offers the most promise for a phase shifter with low insertion loss and reasonable RF power handling capability. For this type of phase shifter configuration to perform properly, it is necessary that the balanced modulator exhibit a very small amount of phase shift as the RF attenuation is varied from minimum to about 30 dB. Beyond this point, the phase shift should exhibit 180° change. The commercially available modulators which were investigated did not demonstrate the necessary amplitude-phase shift characteristics. However, a balanced modulator developed in-house this month exhibits improved amplitude-phase shift characteristics in comparison with the commercial units. This improved performance is achieved by placing a small capacitor in parallel with each of the PIN diodes in the balanced modulator to swamp out the variation of the diode capacitance. The amplitude-phase characteristics of this modulator are compared in Figure 2 with those of a typical commercial model.

The next step of this effort will be the construction of a second balanced modulator and the assembly of a experimental model of the phase shifter.

The activites for next month will continue to emphasize the development of the electronically controlled attenuator and phase shifter.

The activities during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal & Senior Research Engineer	40
Research Engineer	101
Assistant Research Engineer	77

Respectfully submitted:

Hugh W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

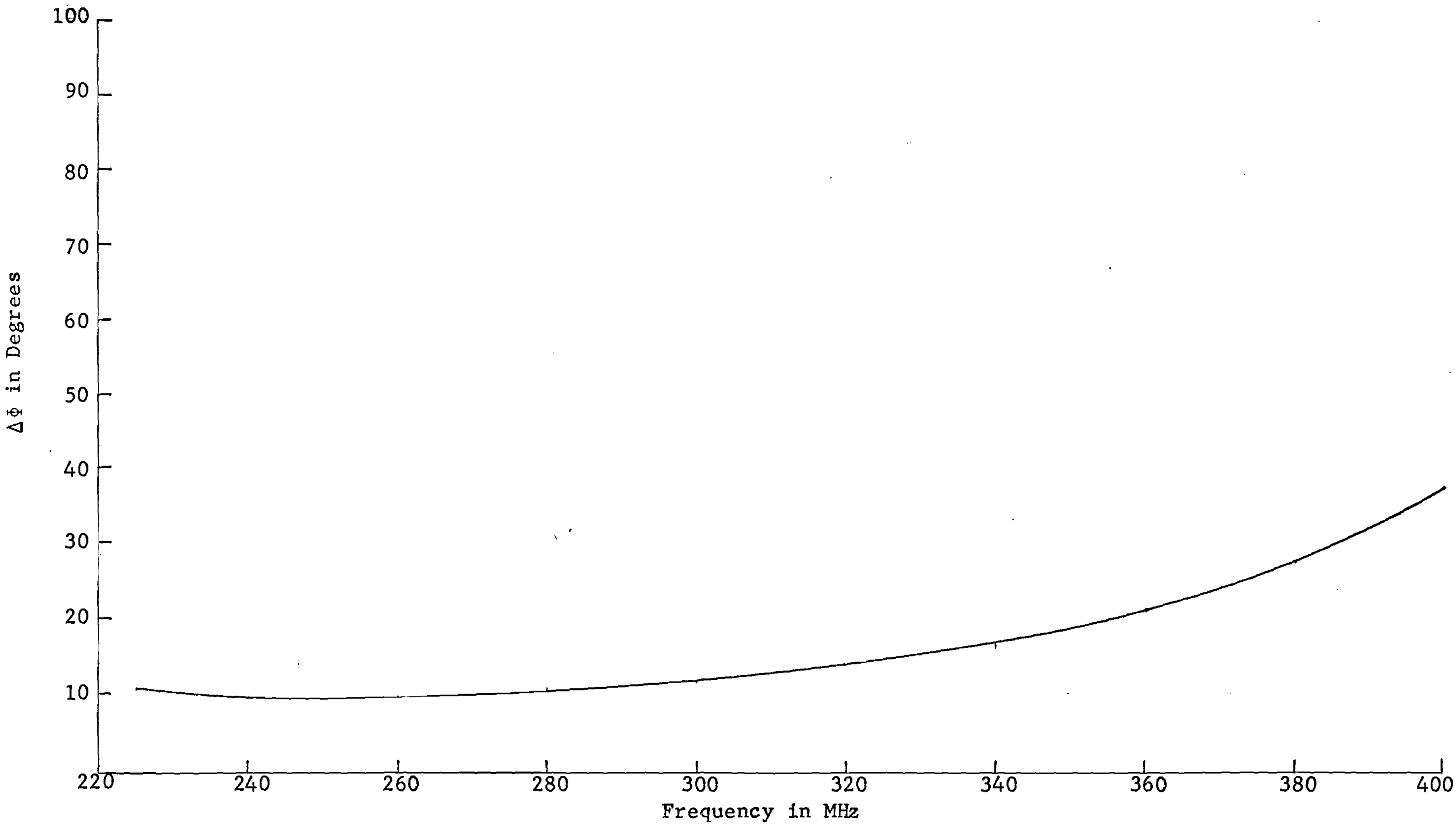

Figure 1. Phase shift characteristics of electrically controlled attenuator as a function of frequency.

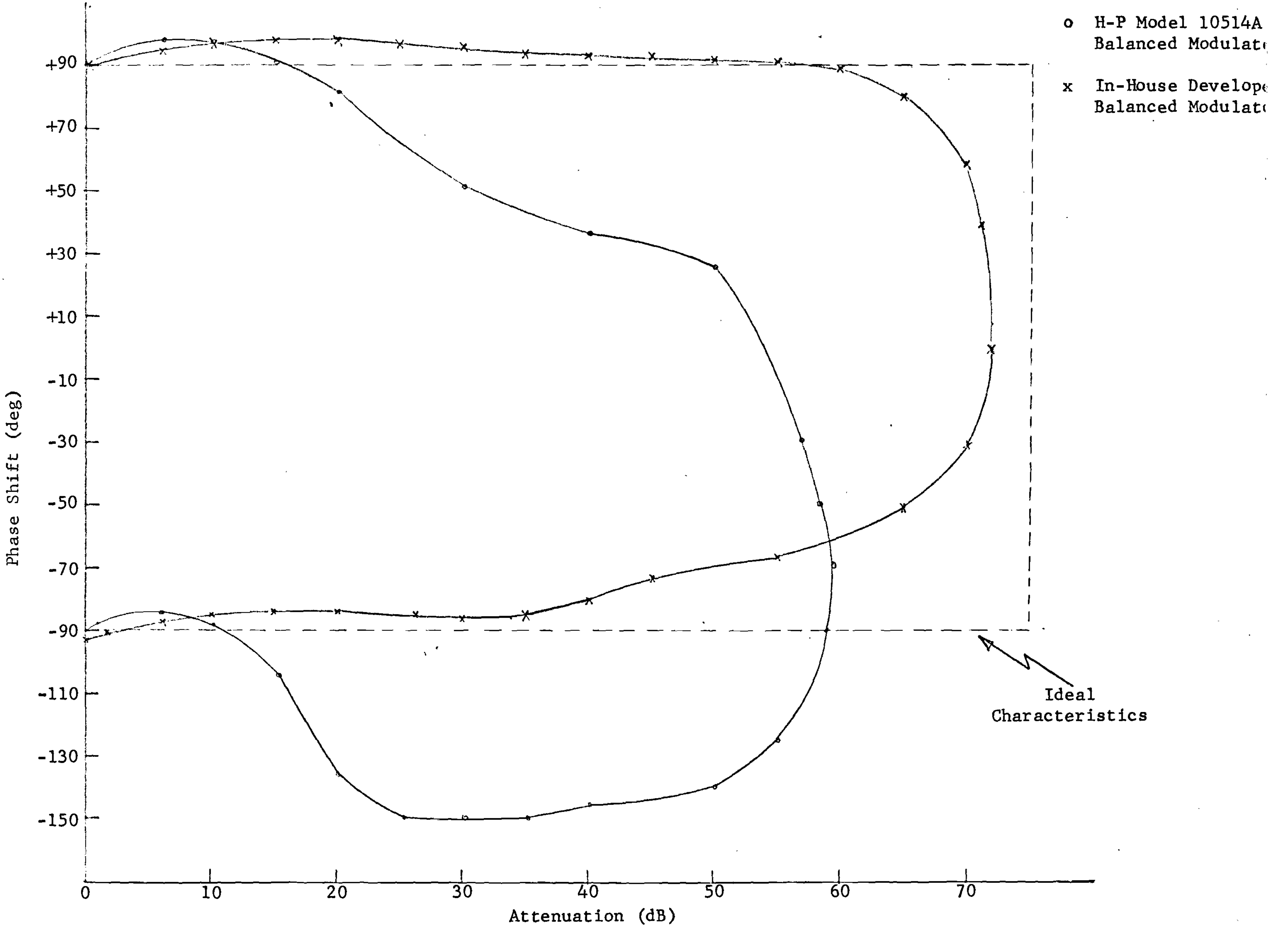

Figure 2. Amplitude-Phase Shift Characteristic of Balanced Modulators.

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

7 August 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 20
This report covers the period from 1 July to 1 August 1969.

Gentlemen:

The activities this month were directed to the development of an electronically controlled attenuator and phase shifter. The attenuator discussed in Status Report No. 19 was modified by repositioning the impedance matching diodes to before and after the sampling and subtraction couplers instead of adjacent to the series diode. In addition, some small tuning capacitances were added. These modifications permitted approximately 0.5 dB reduction in insertion loss to be realized. The mid-band phase variation was reduced to approximately 4 degrees for a 30 dB range of attenuation. The insertion loss, maximum attenuation, and total phase variations for the modified attenuator are shown in Figure 1.

A second attenuator was constructed in order to examine the feasibility of cascaded operation. Some interaction between attenuators was observed. The total phase variation is comparable to a single attenuator near the middle of the frequency range, but, as Figure 2 shows, the phase shift is much greater near the ends of the operating range.

High dielectric constant stripline material has been procured and the design of a three-section directional coupler is under way. It is hoped that the flatter coupling characteristic of the multisection coupler will extend the operating frequency range.

An experimental model of the voltage controlled phase shifter was constructed using two balanced modulators of the type described in the previous status report. These balanced modulators are driven through a quadrature coupler. The output from one modulator is variable in amplitude at a phase angle of 0 degrees or 180 degrees and the output from the other modulator is variable in amplitude at either 90 degrees or 270 degrees. The two variable signals are summed at the output port of the phase shifter. With proper level and polarity adjustments of the dc control signals, the output RF signal can be varied in phase a full 360 degrees with an amplitude variation of less than ± 2 dB. The maximum insertion loss of the phase shifter varies from approximately 5 dB at 225 MHz to 11 dB at 400 MHz. Further investigation of circuit layout and construction techniques is planned in an effort to reduce the insertion loss at the high end of the band.

At the present time a control signal processing technique is being designed and constructed to provide the necessary control signals from a single, positive-going input ramp signal.

The activities for next month include the construction of an attenuator employing multisection directional couplers. Further investigation will be made of techniques for reducing the phase shift of the cascaded attenuators at the upper and lower ends of the 225 to 400 MHz range. The shaping network for the dc control signal of the phase shifter will be finalized and techniques for reducing the insertion loss at the high end of the operating frequency range will be pursued.

The activities during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal and Senior Research Engineer	18
Research Engineer	176
Assistant Research Engineer	175

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

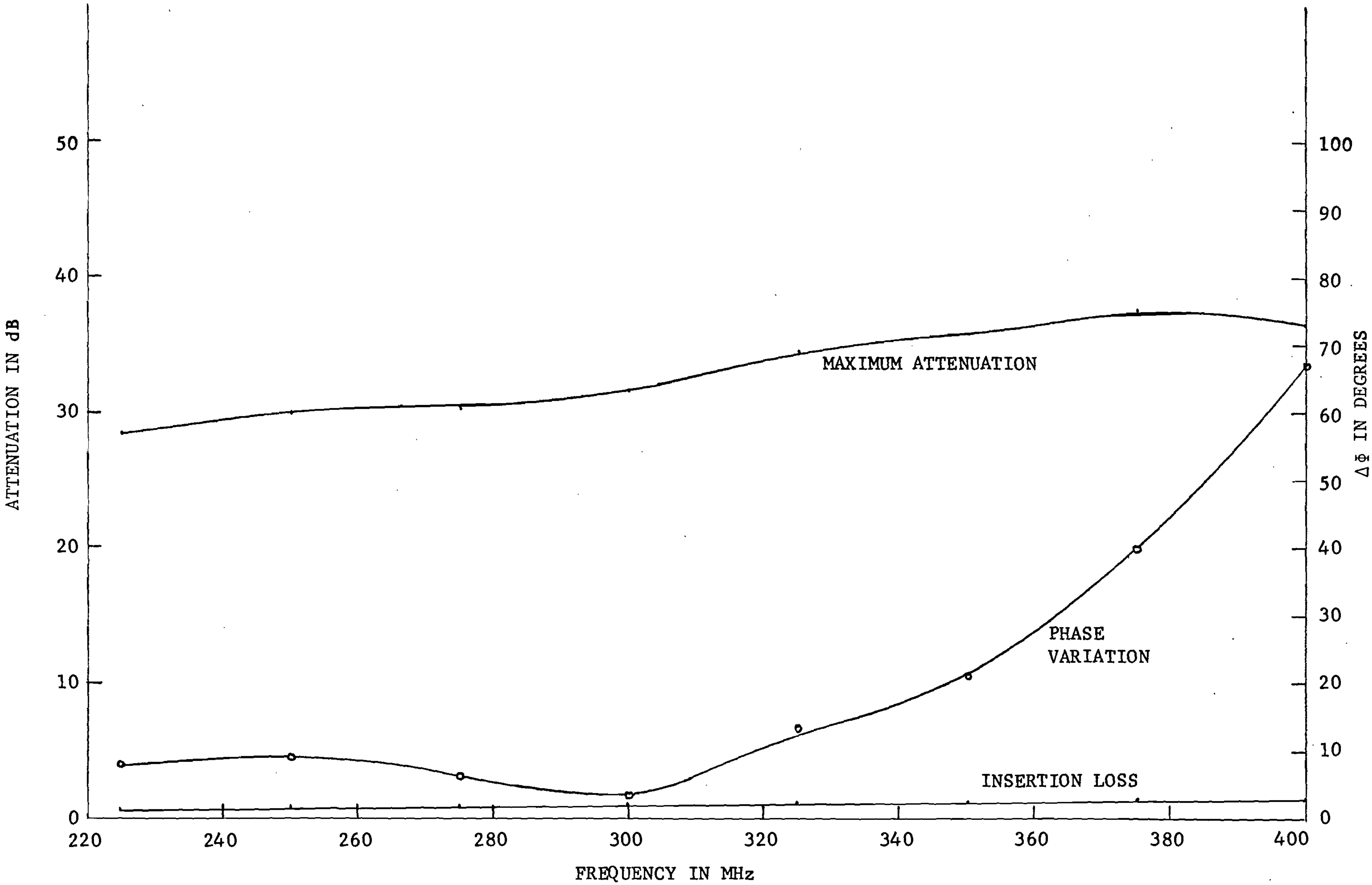

Figure 1. Operating Characteristics of Modified Attenuator.

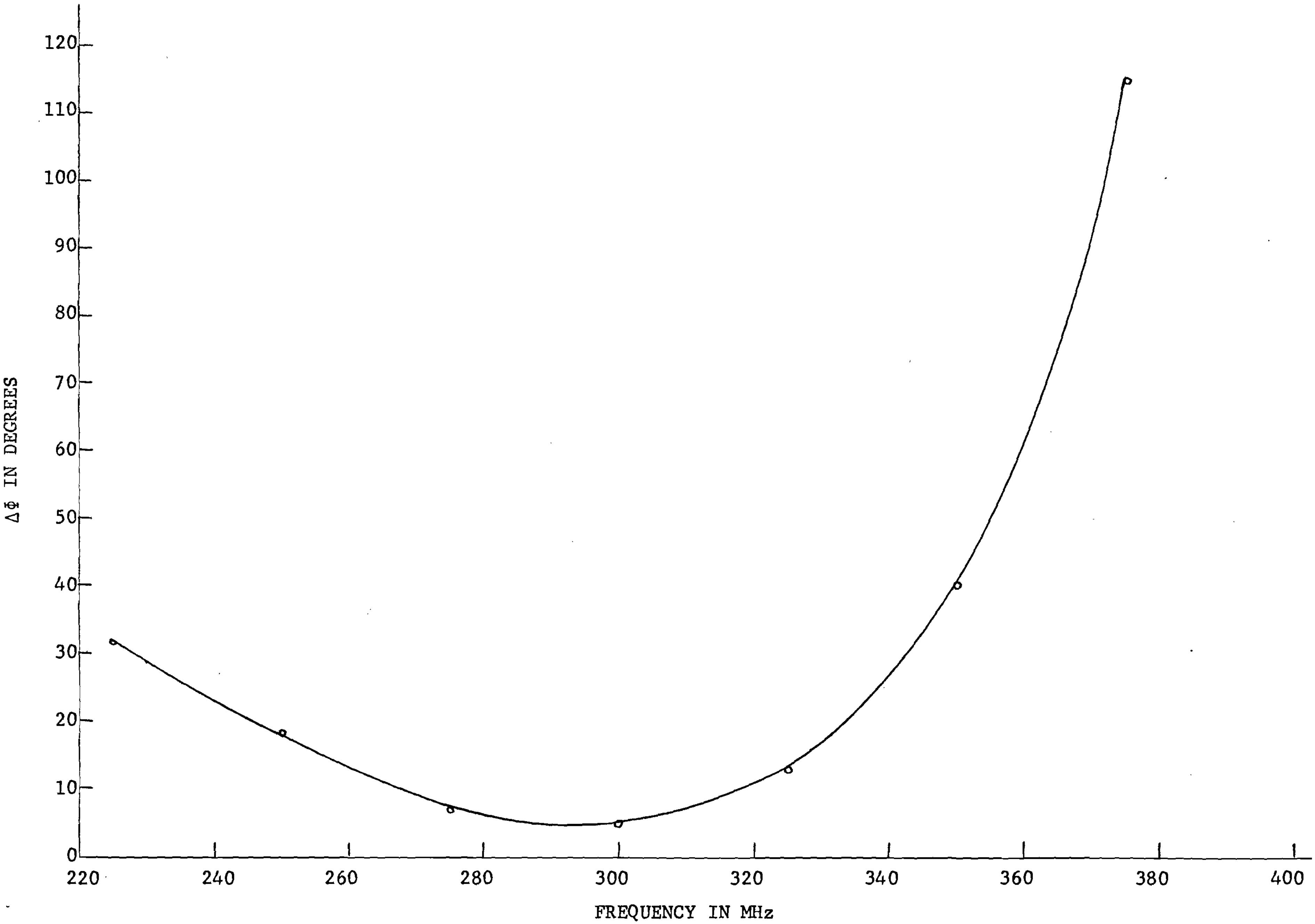

Figure 2. Differential Phase Shift of Two Cascaded Attenuators.

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ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

4 September 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 21
This report covers the period from
1 August to 1 September 1969.

Gentlemen:

The activities this month were directed to continued development of the electronically controlled phase shifter and attenuator.

Three-section, maximally flat directional couplers were designed and constructed of high dielectric constant (ϵ_r = 15) material in an effort to extend the operating frequency range of the current attenuators. The coupling characteristics did not show the improved flatness to be expected from a multisection design and the coupling value was measured to be 13 dB instead of the designed 10 dB. This performance seems to indicate that the dielectric constant of the material is some value other than 15 as purported by the manufacturer. An improved coupler will be necessary before any conclusions can be made of the effectiveness of this approach toward expanding the operating frequency range of the current attenuators.

A Unitrode Corporation high power PIN diode was driven with a one watt signal. Measurements with the single diode showed that all harmonics were at least 60 dB down from the fundamental in the worst case. Such low product generation indicates that use of the high power diodes will permit the attenuator to be used in applications which demand highly linear devices.

Also during the past month, efforts were directed toward the completion of the design and final construction of the voltage controlled phase shifter and associated control signal processor. Presently, the phase shifter is capable of providing a full 360° phase shift for signals in the frequency range of 225 to 400 MHz. The maximum input VSWR of the phase shifter is 2.5:1 and the maximum output VSWR is 2.7:1. Its insertion loss and amplitude ripple characteristics are as reported earlier.

The phase shifter has been designed as a small, self-contained unit, complete with its own power supply to permit its use without additional equipment.

The final report covering all phases of the technical program to date is under preparation and is scheduled for delivery by 30 September 1969.

The activities during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal and Senior Research Engineer	18
Research Engineer	141
Assistant Research Engineer	132

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

1 October 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Title: "Filter Synthesis Techniques"

Subject: Contract Status Report No. 22
This report covers the period from
1 September to 1 October 1969.

Gentlemen:

The activities this month were directed to the continued development of the electronically controlled phase shifter and attenuator.

The three-section, maximally flat directional coupler was redesigned using exact analytical expressions for the transmission line dimensions. The calculations showed that some of the nomographic values were in error by as much as 30 per cent. The calculated line spacings were less, which would produce higher coupler values. A coupler has been constructed using the calculated line dimensions but has not yet been evaluated.

Measurements of the residual coupling through the Unitrode Corporation PIN diodes indicate a higher degree of coupling than exhibited by the lower power diodes. The higher residual coupling requires a higher signal level for cancellation. Using 10 dB couplers in the auxiliary path, adequate nulling of the residual signal could not be obtained. An 8 dB coupler to supply the higher level cancellation signal has been designed and constructed.

Final construction of the voltage controlled phase shifter and associated control signal processor has been essentially completed. The entire system, including the power supply, is contained in a small, less than 0.25 ft^3, aluminum case. The control signal processor and the $\pm$ 15 volt power supply have been constructed on three plug-in printed circuit cards which are inserted from the rear of the case. The UHF phase shifter is mounted directly behind the front panel. The control signal processor includes an input operational amplifier with a front panel gain control to provide gain variations from unity to 40 dB and an integrating type phase lag network which may be switched in or out as desired. The combination of the variable gain input amplifier and the phase lag network permit the voltage controlled phase shifter to be readily incorporated into a closed loop control system.

A report covering the technical activities of the project to date is being prepared. Appropriate additions covering the project activities through the remaining time period will be made prior to submission.

The activities during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month:

Classification	Hours
Principal & Senior Research Engineer	5
Research Engineer	162
Assistant Research Engineer	176

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

6 November 1969

Rome Air Development Center
Procurement Division (EMKC)
Griffiss Air Force Base, New York 13440

Attention: Mr. Joseph Zasa
Contracting Officer (EMKC)

Reference: Contract No. F30602-68-C-0080

Subject: Contract Status Report No. 23
This report covers the period from 1 October to 1 November 1969

Gentlemen:

The activities this month were directed to the continued development of the electronically controlled phase shifter and attenuator.

A voltage controlled attenuator was constructed using Unitrode Corporation PIN diodes and 8 dB directional couplers. The attenuator exhibited an insertion loss of 2 dB and a maximum attenuation of 27 dB. Less than 15 degrees total phase variation with attenuation was observed over the frequency range of 220 to 340 MHz. Another model of this attenuator is under construction.

The development effort on the UHF voltage controlled phase shifter has been directed toward reducing the insertion loss. It has been observed that the diode current level, the broadband transformers and the circuit configuration affect the insertion loss properties of the diode bridges. Up to 30 ma of diode current is necessary for minimum diode loss. To supply this much drive current, modifications of the control signal processor to include the addition of a current amplifier at the outputs are planned. Measurements of the characteristic impedance of the broadband transformers show them to be near 75 ohms. Various winding configurations are presently being evaluated to determine the correct wire size and number of turns to achieve a 50 ohm characteristic impedance. Component and conductor configuration also affect the insertion loss. A transmission line configuration is being employed throughout to improve the impedance match and minimize this loss. These procedures not only reduce the insertion loss through the diode bridges but also improve the impedance match at the directional coupler ports which reduces the insertion loss through the coupler.

The planned activities for next month include continued efforts to refine the operating characteristics of the voltage controlled attenuator and phase shifter.

The activities during this month were essentially in conformance with the projected work schedule.

The following level of engineering effort was devoted to the project this month.

Classification	Hours
Principal Research Engineer	9
Research Engineer	84
Assistant Research Engineer	158

Respectfully submitted:

H. W. Denny
Project Director

Approved:

D. W. Robertson, Head
Communications Branch

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February 1970

FILTER SYNTHESIS TECHNIQUES

Georgia Institute of Technology

Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

FILTER SYNTHESIS TECHNIQUES

H. W. Denny
C. S. Wilson
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FOREWORD

This report was prepared by the Electronics Division of the Georgia Institute of Technology, Hinman Research Building, Atlanta, Georgia, under Contract F30602-68-C-0080, Project Number 4540, Task Number 454003. Secondary report number is A-1058-F. The work described was performed under the general supervision of D. W. Robertson, Head, Communications Branch, and H. W. Denny, Project Director. The authors are H. W. Denny and Charles S. Wilson. The contributions of E. E. Donaldson, Jr. and R. A. Byers to the project are acknowledged. The RADC Project Engineer was George A. Long (EMNCI-2).

This technical report has been reviewed by the Office of Information (EMLS) and is releasable to the Clearinghouse for Federal Scientific and Technical Information.

This technical report has been reviewed and is approved.

Approved: SAMUEL D. ZACCARI
Chief, Compatibility Branch
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FOR THE COMMANDER

IRVING J. GABELMAN
Chief, Plans Office

ABSTRACT

Several active filter techniques for the reduction of receiver interference in the 225 to 400 MHz range are described. Positive feedback Q multiplier techniques were extended to include (1) the use of multiple feedback loops to achieve a high order of stable multiplication in each stage and (2) the use of cascaded stages of Q-multiplied resonators to obtain improved skirt selectivity. Negative resistance Q multiplication was achieved over a wide frequency range through the development of a common collector transistor amplifier that exhibits stable negative resistance properties in the UHF region. The negative resistance amplifier was incorporated into a breadboard model of a tunable filter which employs both active and passive stages to produce a high Q response characteristic with high skirt selectivity over the entire band. An AM cancellation filter that achieves suppression of an unwanted signal by cancellation via a synthesized replica of the signal was developed. The breadboard model demonstrated a suppression capability of 30-35 dB for AM signals and about 50 dB for CW signals.

To enhance the capabilities and versatility of UHF active interference suppression filters, linearization techniques for broadband solid state amplifiers were investigated. The application of negative feedback and the use of the push-pull mode of parallel operation provided a significant reduction in harmonic generation while retaining good gain-bandwidth characteristics in amplifiers of one-watt power output capabilities.

EVALUATION

The objective of this work was to discover new methods of designing active filter circuits that would allow closer frequency spacing in collocated communication systems. The effort was concentrated in the 225 to 400 MHz range where the problem was most prevalent. Three avenues of effort were explored in this contract:

1. The development of a three-stage cascaded UHF Q Multiplier.

2. The development of a UHF AM Cancellation Filter.

3. Research into techniques to improve the linearity of broadband UHF amplifiers.

In the development of the Q Multiplier the objective of successively multiplying the Q of three cascaded cavities was not met. Only one cavity actually provided multiplication. The other two were only optimumly coupled without multiplication. Also this multiplication was sufficiently effective over a frequency range of about 20 MHz at the upper end of the UHF frequency allocation, that is from 370 to 390 MHz. There are many problems of cavity tracking and multiple feedback adjustments which must be solved to produce a highly selective multi stage Q multiplier. With the discovery of better voltage controlled tuning devices and high quality stripline resonators development of a multi stage Q multiplier with superior filtering characteristics may become a practicality. Further exploration into this technique could produce worthwhile results. I would say that the objective of this phase was partly accomplished. The difficulties already mentioned prevented total accomplishment.

In the UHF AM Cancellation Filter Development, the feasibility of synthesizing a cancellation signal was proved and the objective accomplished. However, the process is excessively complicated. With the development of more intricate integrated circuits, realistic devices using this principle could be used.

Some work was done on the reduction of harmonics and intermodulation products of broadband transistorized amplifier by linearity improvement. The overall results of this work produced amplifiers that are equivalent to, but no better than, what is commercially available. The objective was not accomplished here. This is an extremely difficult undertaking. The problem lies more in the characteristics of the transistor than in the external circuitry. Significant improvement in transistor characteristics may be necessary before satisfactory linear amplifiers are produced.

GEORGE A. LONG
Effort Engineer

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SECTION I

INTRODUCTION

Increased demands for communications channels in the 225 to 400 MHz range have made it necessary to reduce the widths of the guardbands used to separate these channels. The resulting spectrum crowding has greatly increased the problem of adjacent and co-channel interference. The use of higher powered transmitters and more sensitive receivers has intensified the problem. This combination of high level signals, highly sensitive receivers, and close channel spacing places severe requirements on RF filters for interference reduction.

Crowding of the spectrum between 225 and 400 MHz is approaching the point where conventional passive devices do not provide adequate filtering action. Passive devices are limited in the degree to which they can solve current interference problems because, to provide the required Q and skirt selectivity, they must be impractically large.

In recent years, the technology of the design and analysis of active filters has progressed rapidly. The initial impetus to active filter development has been provided by low frequency requirements. The use of active techniques in the low frequency region has made it possible to construct physically small filters which are compatible with miniaturized systems.

In view of the advantages which have been demonstrated at lower frequencies, i.e., improved performance and/or significant reduction in the size of filters, a study of the application of active filter techniques in the VHF and UHF regions was performed at Georgia Tech under contract F30602-C-67-0066 [1]. Through the efforts of this program and a previous program [2], the feasibility of signal cancellation and Q multiplication in the 225 to 400 MHz range has been verified.

Although the active filters demonstrated the feasibility of specific techniques, they were limited in their power handling capabilities and/or in their frequency range of operation. In particular, the Q multiplication technique was limited by the power handling capabilities of the available broadband solid state amplifiers. Consequently, a major emphasis in this program was placed on the development of higher powered amplifiers with a high degree of linearity.

The further development of Q multiplication techniques was pursued through the use of multiple feedback loops to stably obtain high orders of multiplication, the use of cascaded stages of multiplied sections to obtain greater skirt selectivity, and the application of negative resistance techniques to obtain a greater operating frequency range.

Negative resistance Q multiplication was employed in a breadboard model of a tunable bandpass filter to produce an improved Q response with high skirt selectivity over the entire 225 to 400 MHz range.

This report describes the activities in the above areas and summarizes the findings of these studies. In addition, a description of a refined AM cancellation system is presented to demonstrate the suppression capabilities of a technique which synthesizes the interfering signal and uses the synthesized replica to cancel the unwanted signal.

SECTION II

Q MULTIPLICATION TECHNIQUES

A. Positive Feedback

The basic positive feedback Q multiplier configuration is shown in Figure 1. To realize very high Q response characteristics with a single loop, either a resonator with a high initial Q must be employed or a very high multiplication factor must be realized. High loaded Q's in passive devices are generally achieved only in physically large devices. Such large devices are incompatible with compact solid state equipments and, consequently, the smallest sized resonator is desired. Unfortunately, the smaller devices exhibit lower Q's which require a high multiplication factor. System stability becomes difficult to maintain as the multiplication factor increases [3].

One method that can be used to avoid the instability problems normally associated with very high multiplication factors is the use of successive stages of multiplication. Figure 2 illustrates the use of multiple stages to obtain a high effective multiplication factor. By achieving the desired multiplication factor in two steps rather than in a single step, improved stability can be expected. For example, a small coaxial cavity with a natural Q of 160 was incorporated into a two stage multiplier to achieve an effective Q greater than 4000. The net multiplication factor was 25 yet the system stability was comparable to the stability of a single stage multiplier with a multiplication factor of 6 to 7. It is evident that successive stages of Q multiplication can be used to realize extremely narrow bandwidth responses from passive resonators of moderate Q.

Although the 3 dB bandwidth is commonly used as a figure of merit for comparing various resonant structures, other characteristics are important for the reduction of adjacent channel interference. For example, the skirt selectivity is a measure of the rate of increase of attenuation outside the immediate passband. The selectivity of a bandpass filter is a function of the number as well as the Q of resonators in the filter.

The substitution of multiple resonators for a single resonator in the Q multiplication network immediately suggests itself as a means for achieving high Q and steep skirt selectivity. However, this approach is difficult to realize [4] because the phase shift through the resonators is difficult to match in the feedback loop. Figure 3 illustrates a possible approach to obtaining high Q performance with increased skirt selectivity. In this system, two active filters are cascaded which effectively doubles the attenuation roll-off rate on the skirts of the selectivity curve without degrading the Q of the individual filters. This system has the advantage that either the filters may be synchronously

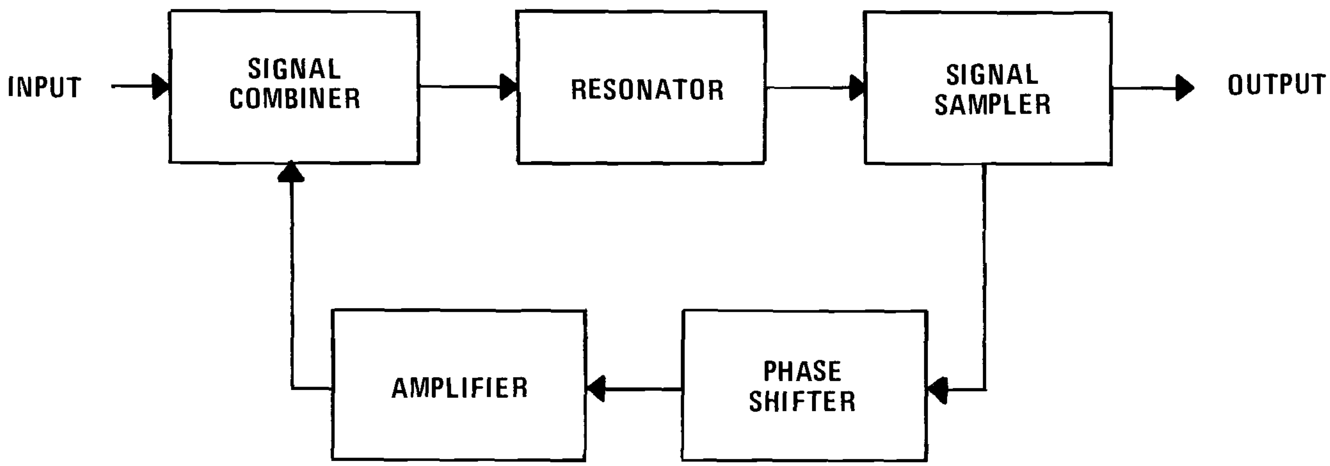


Figure 1. Block Diagram of the Basic Q Multiplication Network Configuration.

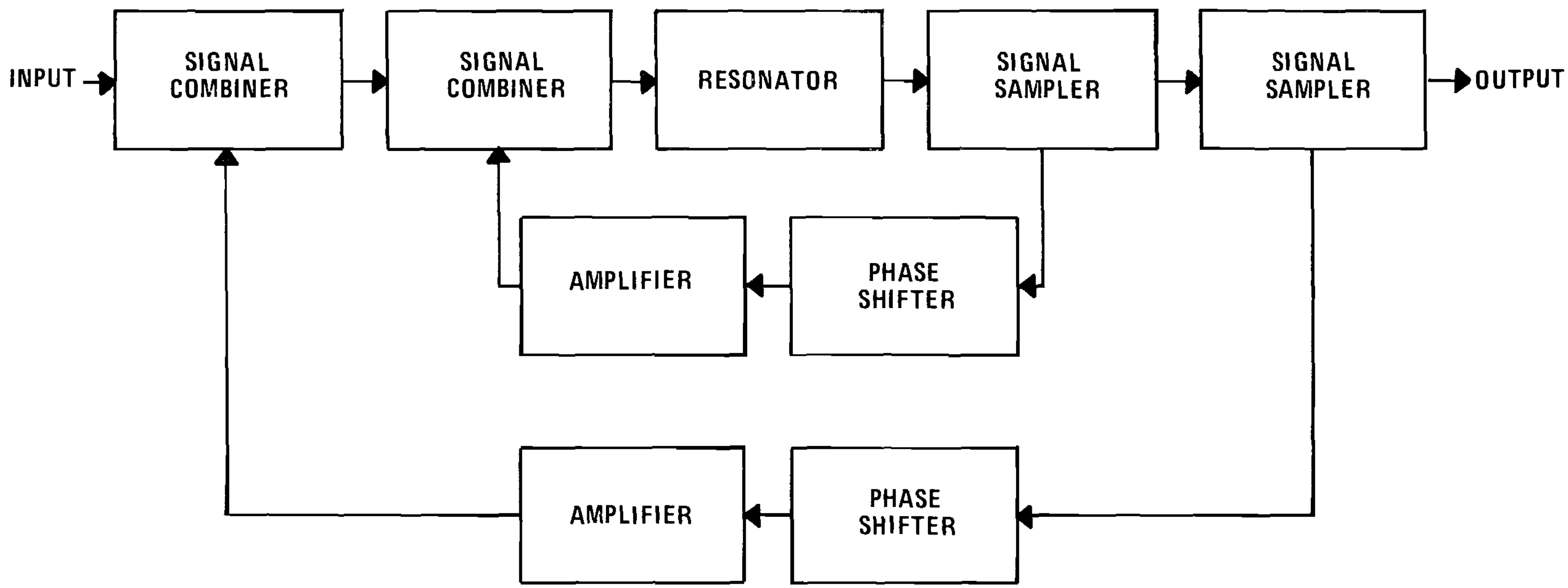


Figure 2. Block Diagram Showing the Two Stage Q Multiplication Technique.

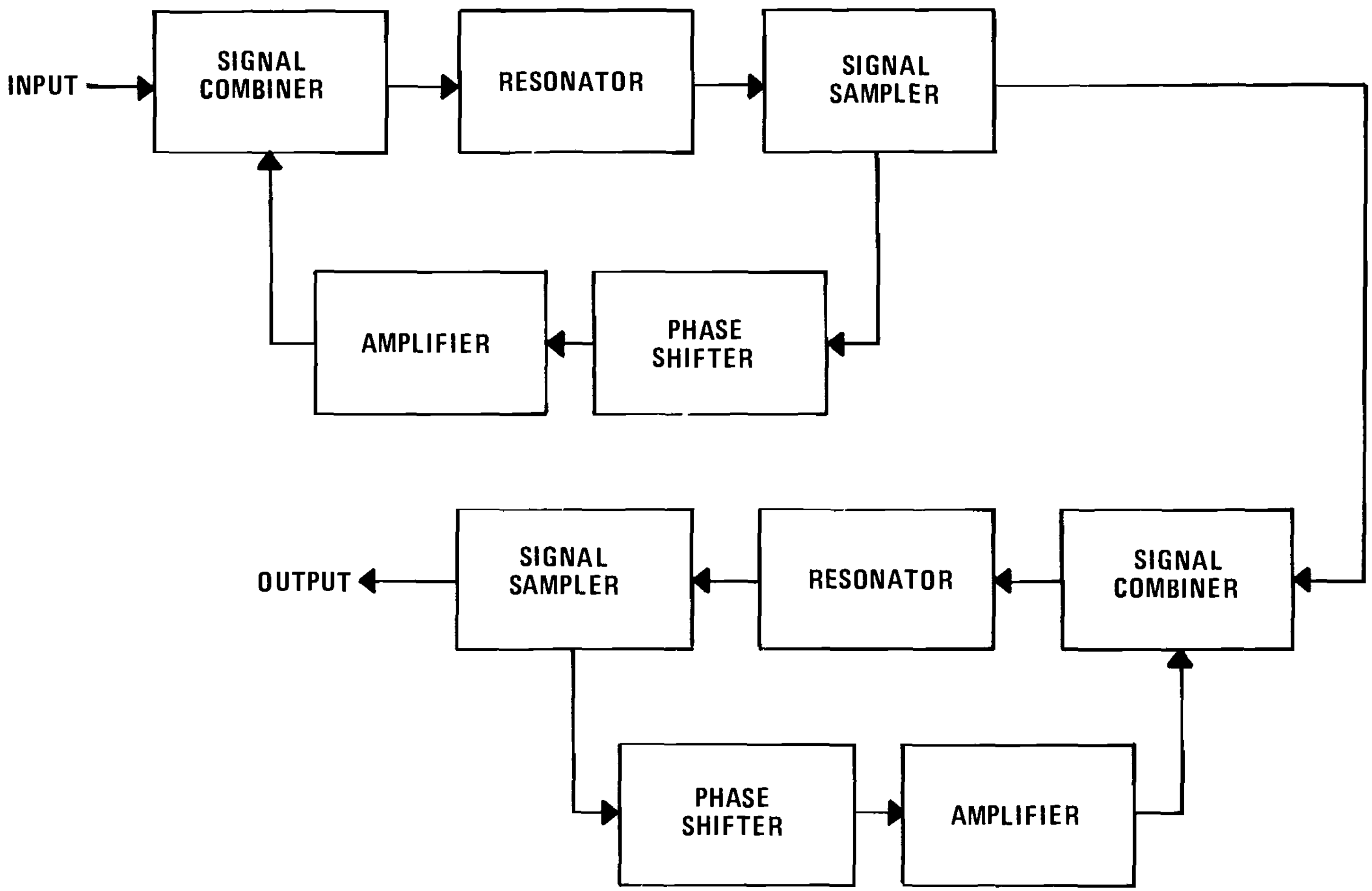


Figure 3. Block Diagram Showing the Cascade Operation of Resonators of Multiplied Q to Obtain a Double Tuned Response.

tuned for minimum bandwidth or they may be stagger tuned to produce a flat passband region with more rapid attenuation roll-off in the stop-band. The response characteristics of one, two, and three cascaded stages of Q multiplication are illustrated in Figure 4. Shown for comparison purposes are the response curves of a single cavity and a double cavity coaxial filter. Note that the 60 dB bandwidth of the two stage active filter is 9 MHz compared to the 12 MHz 60 dB bandwidth of the model 156C-2 double tuned cavity filter.

The effectiveness of the active filters for improving the interference rejection properties of a receiver is illustrated in Figure 5. The cross modulation rejection of an AN/APR-4 receiver with its internal preselector is compared with the rejection obtainable when various types of active and passive filters are added to the front end of the receiver. The curves show the significant improvement in the interference rejection which can be achieved with filters of multiplied Q. With only the internal preselector, the AN/APR-4 exhibits 30 dB rejection to an interfering signal spaced 2 MHz from the tuned frequency at 300 MHz. The single cavity filter increases this rejection to 52 dB and the model 156C-2 multicoupler provides an increase in the rejection to 70 dB. The three stage Q multiplier filter increases the rejection of the receiver to the interfering signal to 92 dB for an improvement over the basic receiver of 62 dB, and a 22 dB improvement over the double tuned passive multi-coupler. The maximum cross modulation rejection available out of band to interfering signals was limited to approximately 90 dB with only the internal preselector of the receiver. The added active filters increased this ultimate rejection to greater than 110 dB.

B. Negative Resistance

Another well-known technique of Q multiplication is the use of active networks to produce a negative resistance which in turn supplies some of the energy losses in the resonator. The result is a lower net value of positive resistance and a consequent increase in Q.

A negative resistance device is characterized by

$$e = -iR \quad . \tag{1}$$

The minus sign indicates that the e-i characteristic curve has a negative slope. No physically realizable device can exhibit a negative e-i characteristic over its entire operating range. However, a number of common devices such as the tetrode vacuum tube and the tunnel diode exhibit limited regions of negative resistance. Properly biased within the negative resistance region, such devices can supply power to the input terminals. In other words, the power reflected from the device is greater than the power incident on the device.

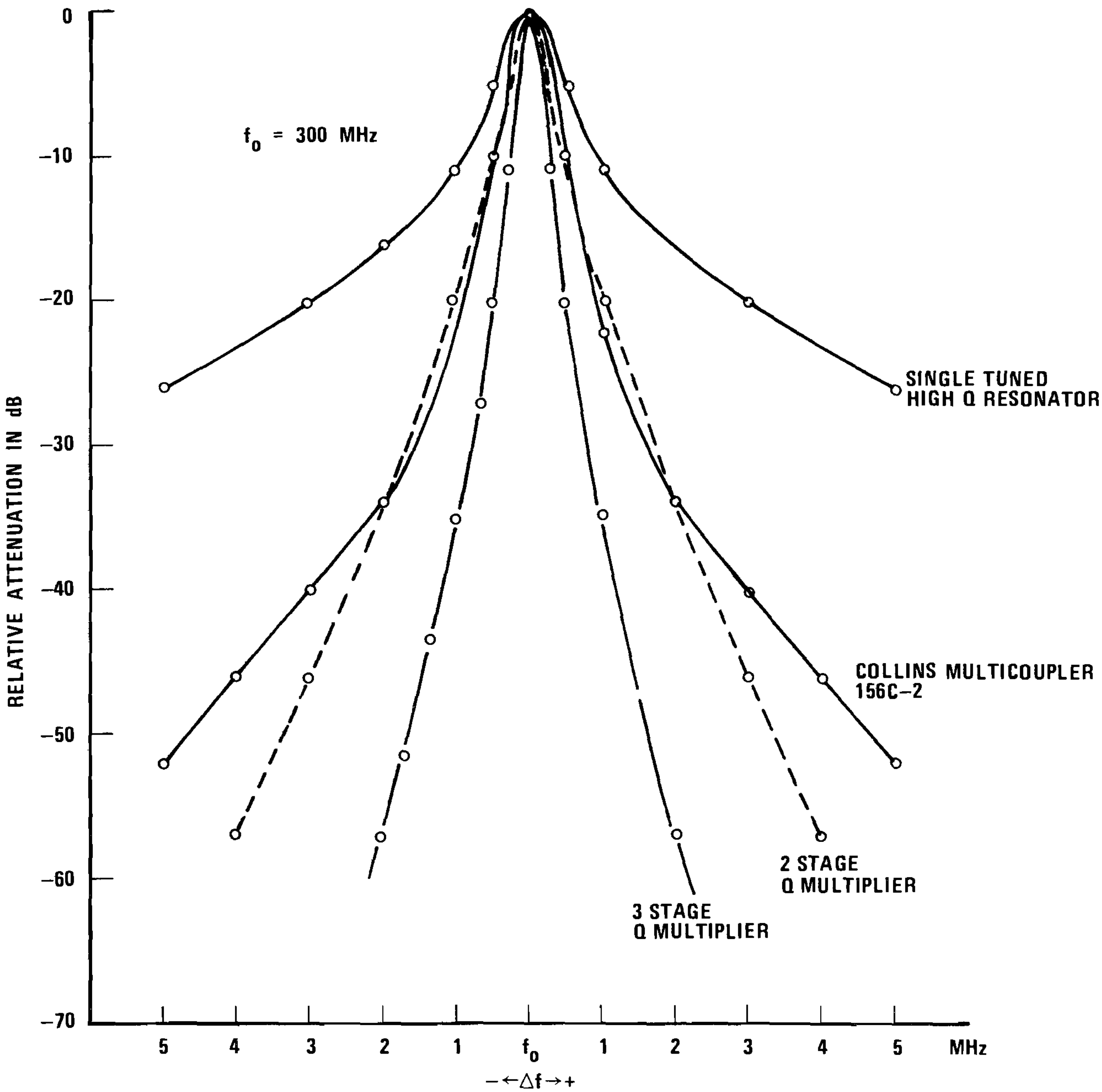


Figure 4. A Comparison of the Response Characteristics of Selected Active and Passive Preselector Types.

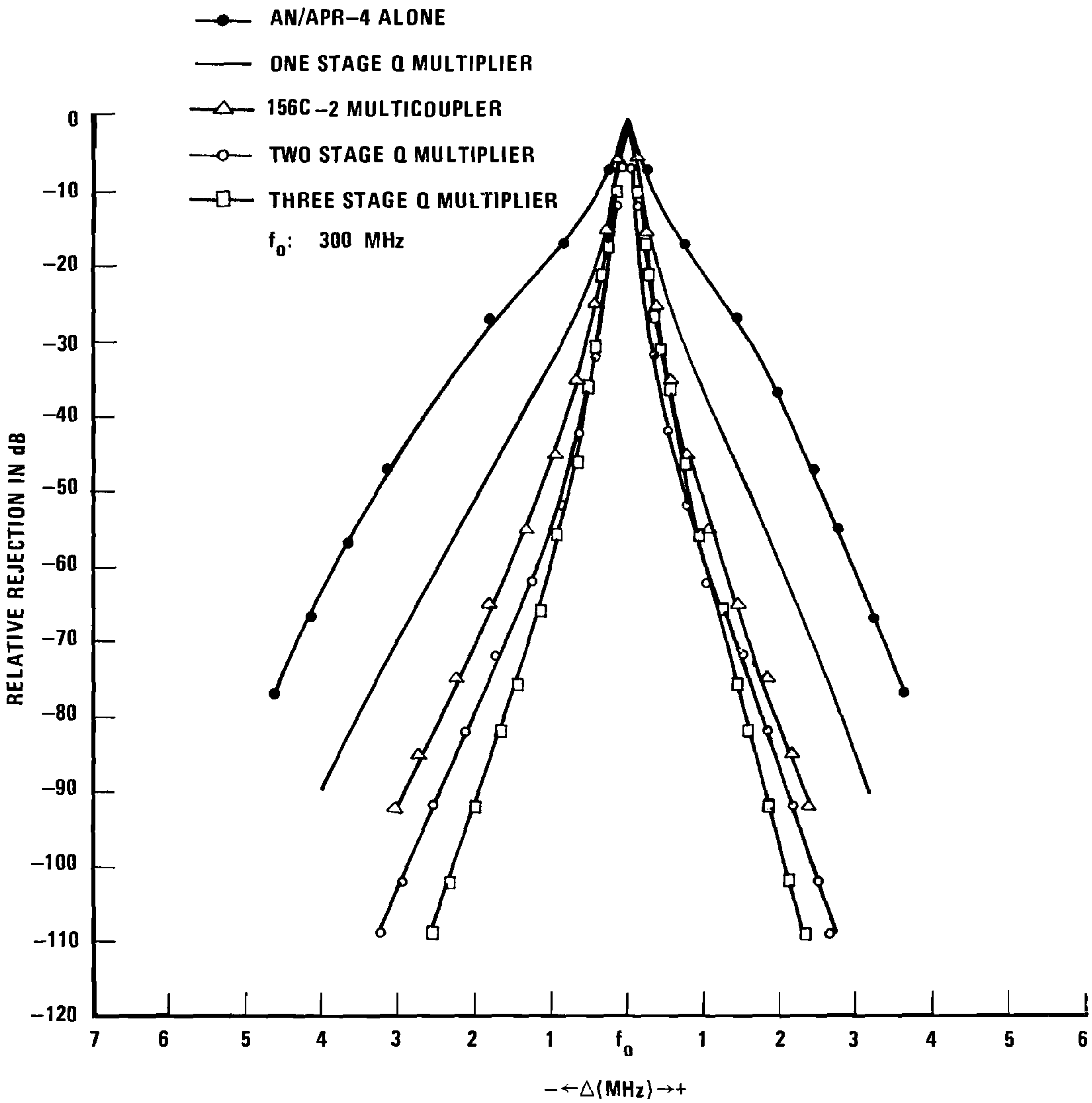


Figure 5. Cross Modulation Rejection Characteristics of a UHF Communications Receiver With Selected Active and Passive Filters Added.

If a transmission line of characteristic impedance Z_o is terminated in an impedance of Z_i, the ratio of the reflected voltage to the incident voltage, i.e., the reflection coefficient, is

$$\Gamma = \frac{Z_o - Z_i}{Z_o + Z_i} \quad . \tag{2}$$

Depending upon the ratio of the Z_o to Z_i, Γ may be positive or negative, but, for Z_i positive, its maximum value is one as shown by Figure 6. If Z_i is negative, however, Γ can have any value between plus and minus one to infinity. A reflection coefficient greater than one indicates that the terminating resistance is supplying power to the transmission line. Except for $Z_i = -Z_o$, the system is stable.

A true negative resistance is a two terminal device. Being a two terminal device, it may be connected in series with or in parallel to a positive resistance to reduce the net total resistance. To maintain stability, the net resistance must remain positive. Negative resistance devices exhibit either open circuit stability or short circuit stability [5]. An open-circuit stable device is controlled by the current passing through the terminals of the device and, as such, is appropriate for a series mode of operation. A short circuit stable device is controlled by the voltage applied across the terminals of the device and thus is appropriate for a parallel mode of operation. Parallel mode devices are of particular interest to UHF Q multiplication applications. They are simple to implement in that they may be used as terminating elements of transmission line sections. The terminated transmission lines may be connected as shunt elements as shown in Figure 7. They may also be coupled into cavity walls or connected across resonant lengths of line to multiply the Q of resonators directly.

The use of tunnel diodes as negative resistance terminating elements is well known. For example, a tunnel diode may be employed as the terminating element of a low-pass filter [6] to produce a low noise, low-pass amplifier. The tunnel diode finds its primary usefulness in low signal level applications. The limited signal handling capabilities of tunnel diodes restrict their application as Q multiplication devices.

A common collector transistor circuit has been suggested as exhibiting a negative resistance characteristic [7]. On the basis of its demonstrated performance at low frequencies, further investigation of its characteristics in the 225 to 400 MHz range was performed. Note that it is not correct to refer to the common collector amplifier as an emitter follower at these frequencies because the emitter voltage does not really "follow" the base voltage as it does at low frequencies. As a negative resistance device, the common collector circuit offers a significant advantage over the tunnel diode in power handling capability.

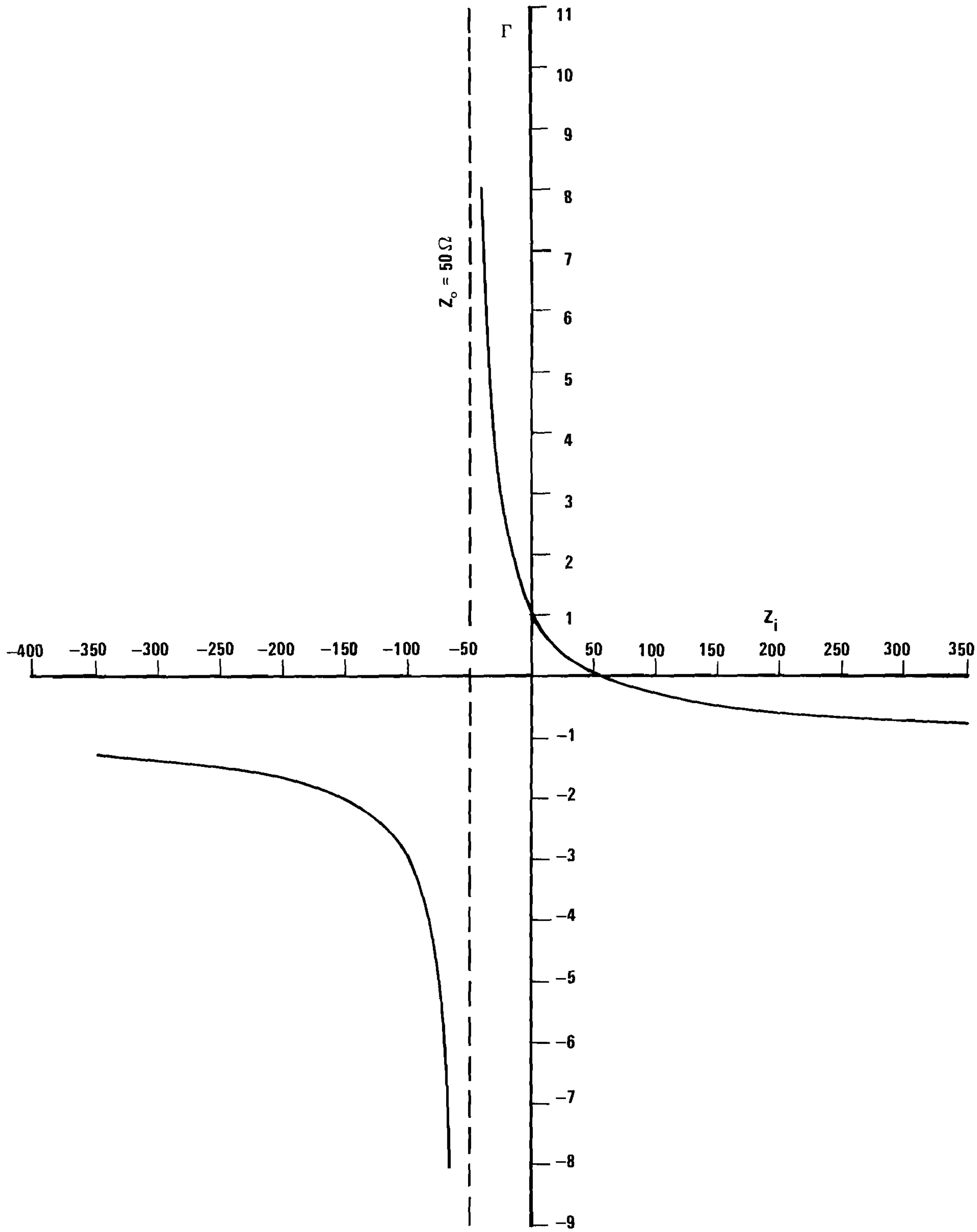


Figure 6. Reflection Coefficient as a Function of Both Positive and Negative Terminating Impedances.

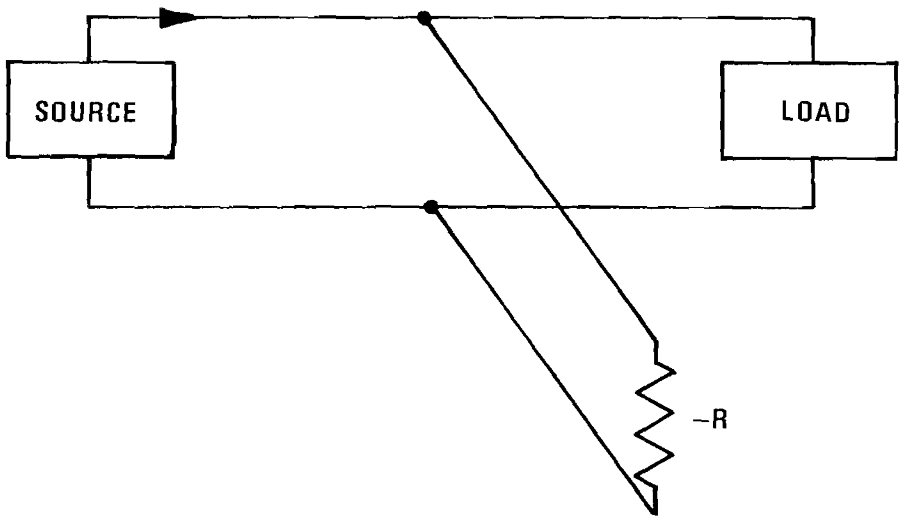


Figure 7. Illustration of the Application of Negative Resistance as a Shunt Element Across a Transmission Line.

Consider the grounded collector amplifier shown in Figure 8. Measurements of the scattering parameters of this amplifier reveal its characteristics at 300 MHz to be

$$S_{11} = 0.8 \ \angle -60^{\circ} \ ; \tag{3}$$

$$S_{22} = 0.83 \ \angle +95^{\circ} \ ; \tag{4}$$

$$S_{21} = 1.66 \ \angle -75^{\circ} \ ; \tag{5}$$

$$S_{12} = 0.52 \ \angle +9^{\circ} \ . \tag{6}$$

The terminal characteristics of the amplifier with an arbitrary load are most readily obtained through the use of signal flow graph analysis techniques. The flow graph of a four terminal network driven by a source, b_s, with a reflection coefficient, Γ_s, and terminated with a load having a reflection coefficient, Γ_L, is shown in Figure 9. If Γ_s is assumed to be zero (i.e., the impedance of b_s is equal to the measurement reference impedance which in this case is 50 ohms), the power flow $b_s b_1$ is equal to the power flow $a_1 b_1$.

The effective input reflection coefficient of the amplifier for the load not matched is [8]

$$T_{a_1 b_1} = \frac{\Sigma T_k \Delta_k}{\Delta} \quad , \tag{7}$$

where

T_k = the gain of the kth forward path,

Δ_k = the value of Δ not touching the kth forward path, and

Δ = 1 - (sum of all individual loop gains) + (sum of the loop gain products of all possible combinations of two non-touching loops) - (sum of the loop gain products of all possible combinations of three non-touching loops) + ...

Thus, for $\Gamma_s = 0$, the effective input reflection coefficient, S_{11}', is

$$S_{11}' = T_{a_1 b_1} = S_{11} + \frac{S_{12} \, S_{21} \, \Gamma_L}{1 - S_{22} \, \Gamma_L} \quad . \tag{8}$$

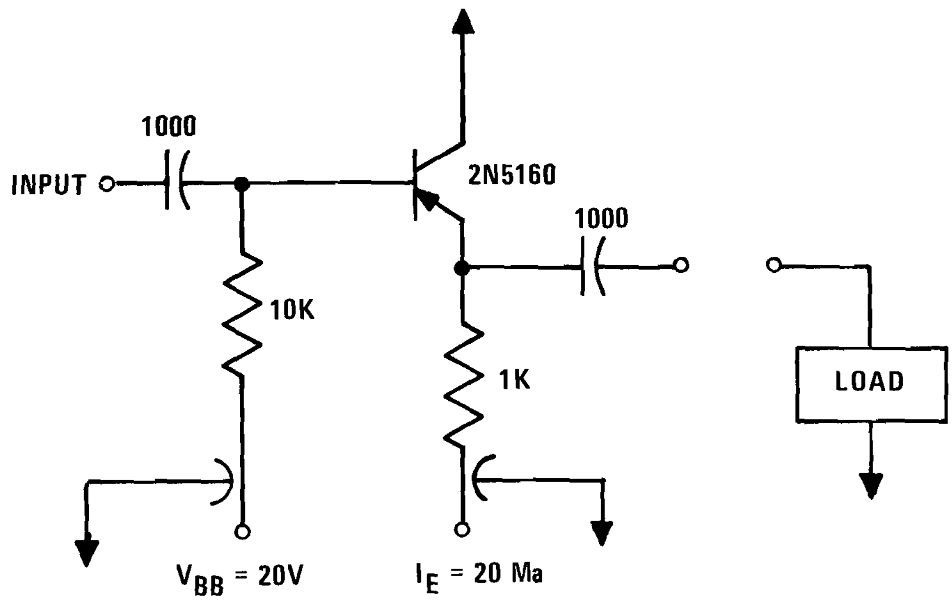


Figure 8. Schematic of a Grounded Collector Amplifier.

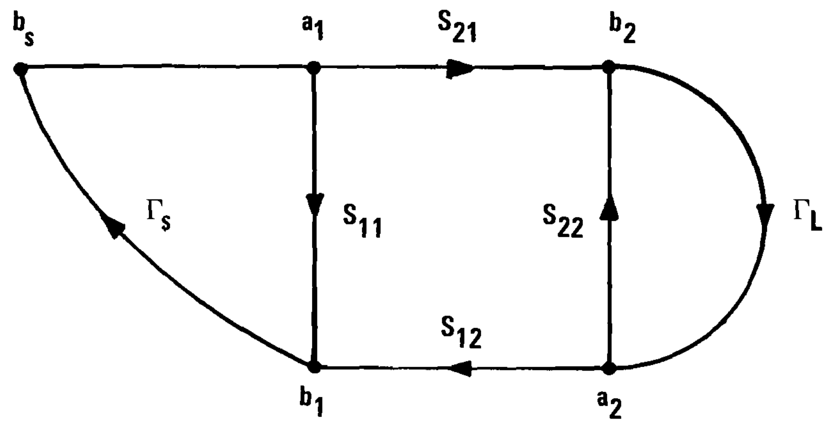


Figure 9. Signal Flow Graph for a Simple Amplifier.

For the transistor with a realizable load

$$|S_{12}S_{22}\Gamma_L| \geq 0 \quad , \tag{9}$$

and

$$|S_{22}| \text{ and } |\Gamma_L| \text{ are } \leq 1 \quad . \tag{10}$$

For stability, it is necessary that

$$S_{22}\,\Gamma_L < 1 \quad . \tag{11}$$

It may be seen from (8), that the circuit will oscillate only if both S_{22} and Γ_L are equal to one. In particular, if S_{22} is less than one at all frequencies, stability is assured.

Substitution of the measured parameters (3)-(6) into (8) yields

$$S'_{11} = 0.8\ \angle{-60^o} + \frac{(0.86\ \angle{-66^o})\ \Gamma_L}{1 - (0.83\ \angle{+95^o})\ \Gamma_L} \quad . \tag{12}$$

Assume a pure capacitive load having a Γ_L of -j1. Then

$$S'_{11} = -\ 2.62 - j3.99 = 4.8\ \angle{-125^\circ} \quad . \tag{13}$$

From (13), it is evident the circuit exhibits a reflection coefficient greater than one and therefore it behaves as a negative resistance in that it supplies more power to the input terminals than was originally supplied by the source.

Figure 10 illustrates the use of a common collector negative resistance amplifier to enhance the Q of a coaxial cavity. Since the source impedance consists of the parallel combination of the cavity output impedance and the other terminal impedance, the source reflection coefficient, Γ_s, is not zero except possibly at specific frequencies. If $\Gamma_s \neq 0$, the conditions for stability are not as well defined as implied by equation 11. The amplifier can be made stable regardless of the tuning point of the cavity by adjusting the emitter load impedance as shown in Figure 11 and by appropriately choosing the cavity output coupling configuration. A high impedance probe was experimentally determined to be the optimum cavity coupling for best Q commensurate

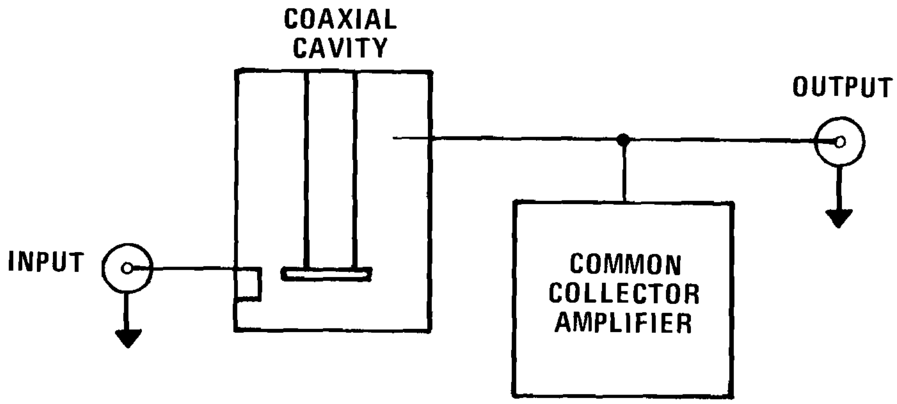


Figure 10. Application of the Negative Resistance Amplifier to the Multiplication of the Q of a Coaxial Cavity.

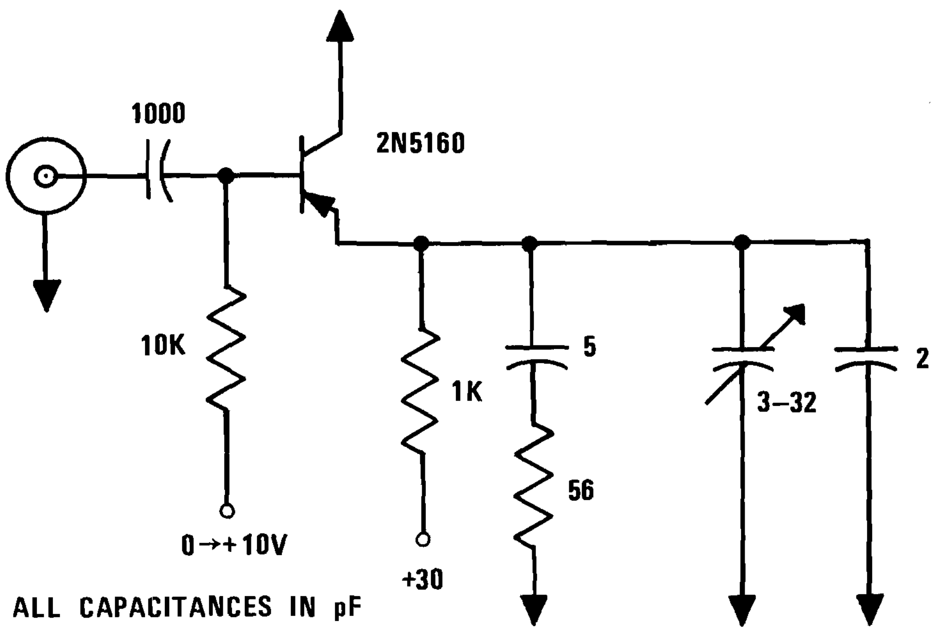


Figure 11. Circuit Diagram of a Stable Negative Resistance Amplifier.

with stable operation over a wide frequency range. Since the transistor characteristics are not constant with frequency, the emitter load capacitor must be trimmed slightly at different frequencies to obtain maximum multiplication.

The effectiveness of the common collector amplifier as a Q multiplier is illustrated by Figure 12. The Q of a cavity with and without Q multiplication is shown as a function of frequency. The cavity terminal impedance as well as the transistor parameters vary with frequency and, consequently, the relative multiplication is frequency dependent.

The common collector amplifier in Figure 11 can typically handle signal levels up to -5 dBm. By using the emitter as the input port with the base as the "output" port, an increase in power handling capability may be expected. This "Inverted Common Collector" configuration has been investigated independently by Adams and Ho [9]. They have shown that this configuration also exhibits negative resistance properties in the UHF frequency region.

C. Q Multiplier Filter

The breadboard model of a tunable bandpass filter that is shown in Figure 13 was constructed to demonstrate the feasibility of active filter techniques in the 225 to 400 MHz region. A combination of negative resistance Q multiplication and lightly loaded coaxial cavities was employed to produce a narrow bandpass response with high skirt selectivity. The negative resistance technique of Q multiplication was chosen because it offered the capability of operating over the entire frequency range. At the time of construction of the filter, a phase shifter capable of operating from 225 to 400 MHz was not available and, therefore, the positive feedback technique could not be implemented over the total range.

The curves of Figure 4 indicate that cascaded resonators are necessary to obtain high skirt selectivity. Single stage Q multiplication achieves reduction of the 3 dB bandwidth and, by virtue of the available gain, produces a relative improvement in stop band attenuation, but it does not increase the slope of the skirt attenuation characteristic. Consequently, in addition to the Q multiplication stage, two passive stages are included to provide high skirt selectivity. Additional amplifiers are provided to establish the noise figure of the system and/or to provide isolation between the tuned elements. Two selectable attenuators of the design shown in Figure 14 are included to limit the gain in certain frequency regions and to provide impedance stabilization for the negative resistance amplifier.

The active and passive elements are combined in the system shown in the block diagram of Figure 15 to produce a bandpass filter response having a 3 dB bandwidth of 200 ±50 kHz, a 6 dB-to-60 dB selectivity ratio of 0.07 and a skirt rolloff attenuation slope of 18 dB/octave. A minimum of 30 dB gain is available at any tuned frequency between 225 and 400 MHz. The noise figure of the filter is approximately 20 dB.

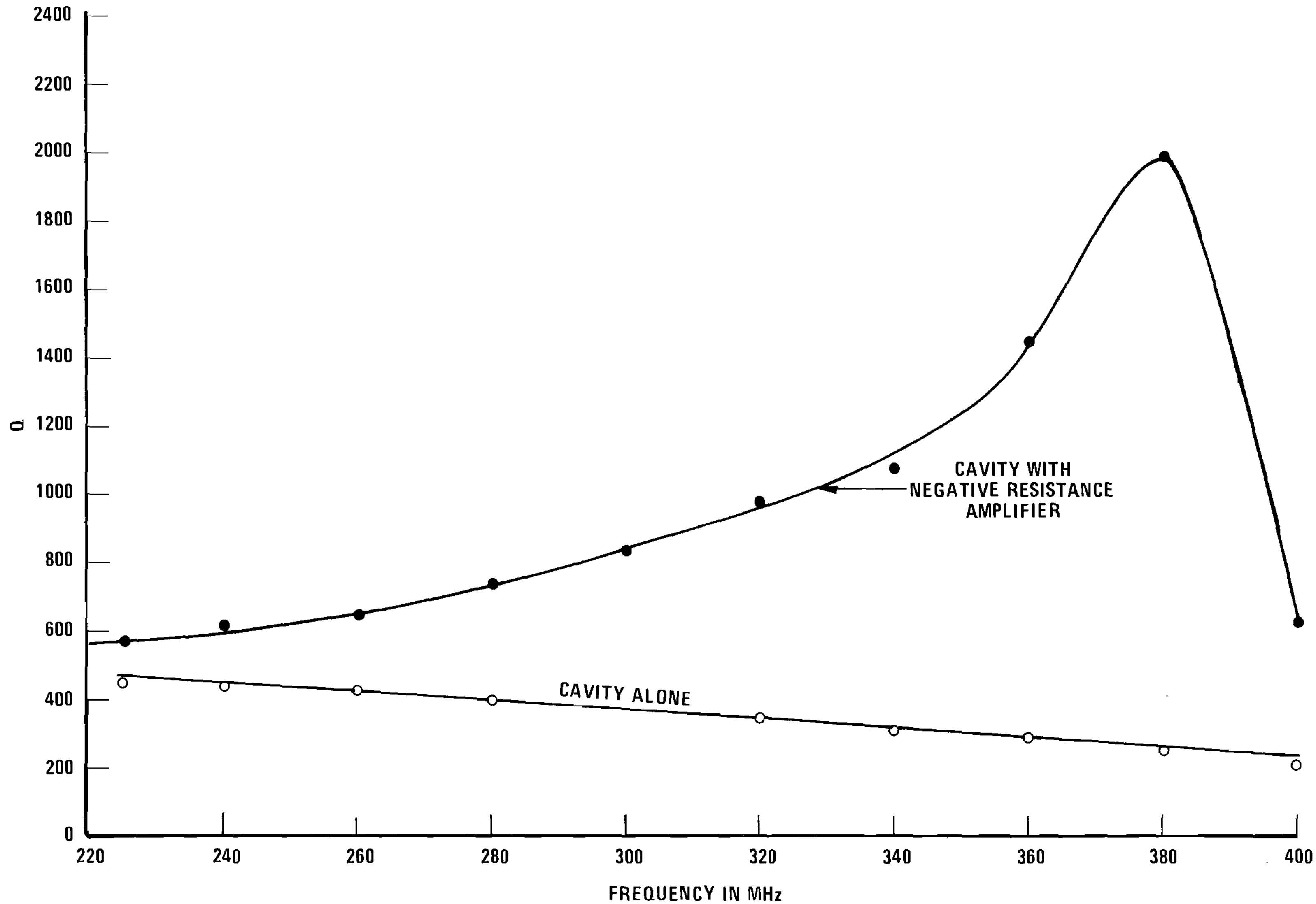


Figure 12. Cavity Effective Q as a Function of Frequency with Negative Resistance Q Multiplication Applied.

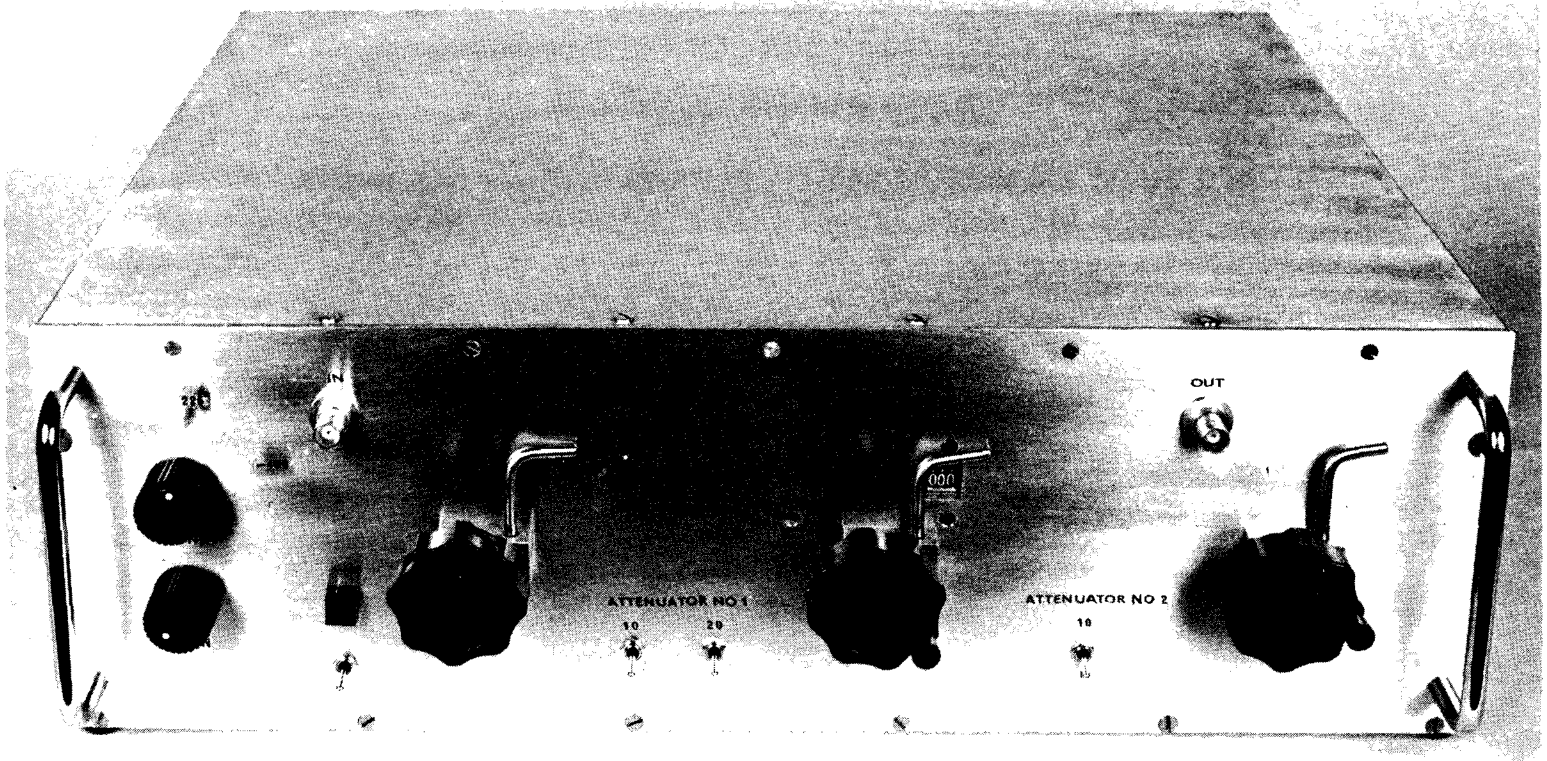


Figure 13. Photograph of the Cascaded Q Multiplier Filter.

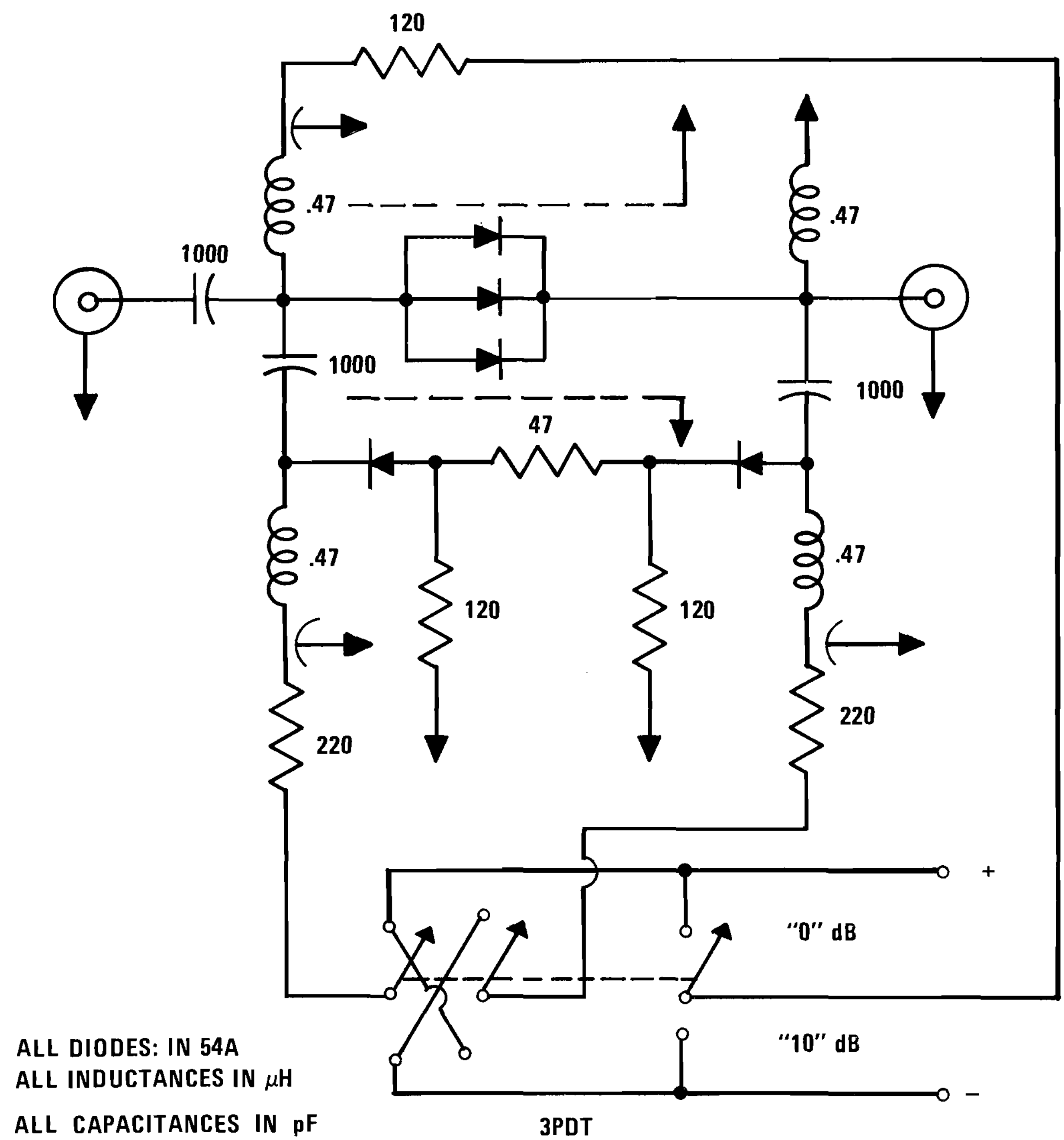


Figure 14. Schematic Diagram of Electronically Switchable Broadband Attenuator.

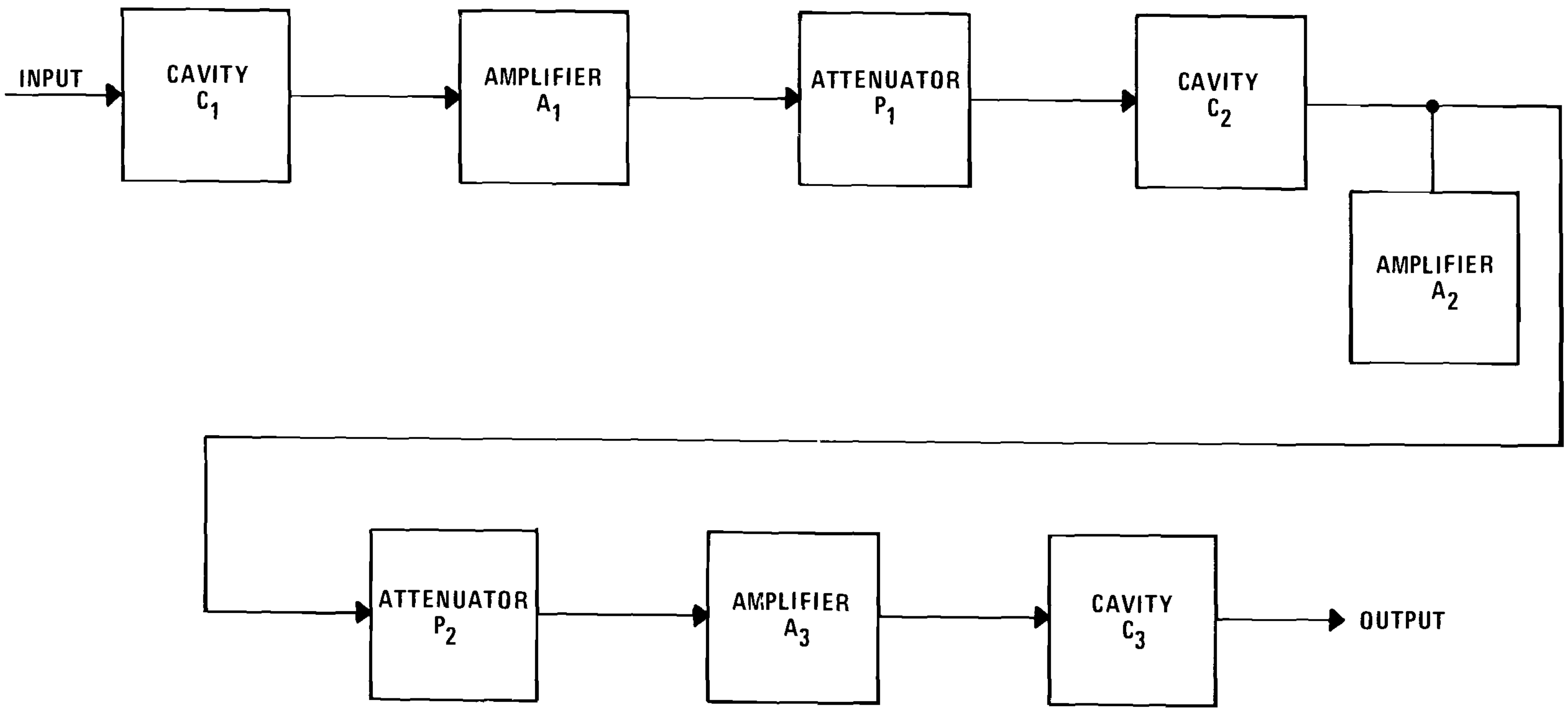


Figure 15. Block Diagram of the Cascaded Q Multiplier Filter.

System Description: The input signals from the antenna are first filtered by cavity, C_1. The coupling loops in C_1 are adjusted to provide a moderate loaded Q of approximately 500 with an insertion loss of typically 5 dB across the frequency range.

A broadband amplifier, A_1, provides approximately 28 dB gain to effectively establish the noise figure of the filter. The tangential sensitivity of A_1 is about -105 dBm and the 1 dB compression level is -5 dBm for a dynamic range of approximately 100 dB. The input VSWR is less than 1.5:1 and the output VSWR is less than 2.0:1 over the frequency range.

Attenuator P_1 can be set at 0, 10, and 20 dB with front panel switches. P_1 provides a coarse gain adjustment for the filter and adds additional impedance stabilization to the second cavity, C_2.

The input coupling to C_2 is a small inductive loop which is adjusted to provide optimum Q commensurate with moderate insertion loss at the low end of the frequency range. Output coupling is provided with an E-field probe whose length and position are adjusted to provide the proper impedance for stable operation of amplifier A_2. Amplifier A_2 is a common collector configuration which operates in parallel to the output port of C_2 and provides effective multiplication of the Q of the cavity.

P_2 is an attenuator whose value is selectable at either 0 or 10 dB. The 10 dB position is necessary to assure stability of A_2 in the frequency region of 350-400 MHz.

To provide a high degree of isolation between A_2 and cavity C_3 over the entire band, amplifier A_3 is provided. A_3 is a broadband amplifier which provides the required isolation as well as supplying approximately 20 dB gain.

Since the net gain from the input of C_1 to the output of A_3 is high across the band, high insertion loss can be tolerated in C_3. Therefore, small coupling loops oriented to realize the maximum possible Q are used in C_3.

The tangential sensitivity of the filter across the 225 to 400 MHz range is shown in Figure 16. A 5 to 10 dB improvement in the sensitivity could be realized by reducing the insertion loss of cavity C_1 and improving the noise figure of amplifier A_1. The effective filter Q as a function of frequency is shown in Figure 17. Note that higher Q's are evident between 300 and 400 MHz which is to be expected because of the higher multiplication provided by the negative resistance amplifier in this region.

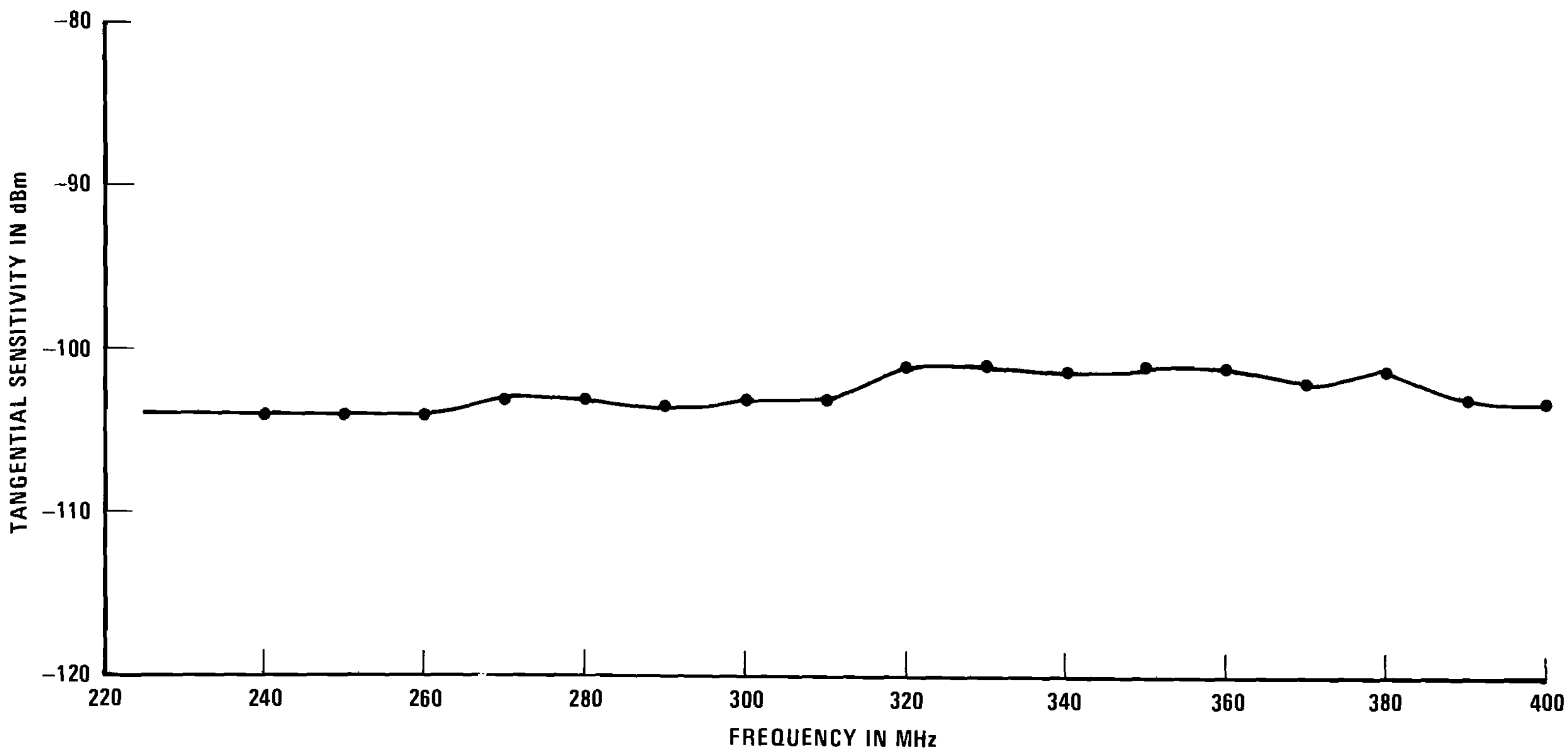


Figure 16. Tangential Sensitivity of the Cascaded Q Multiplier Filter.

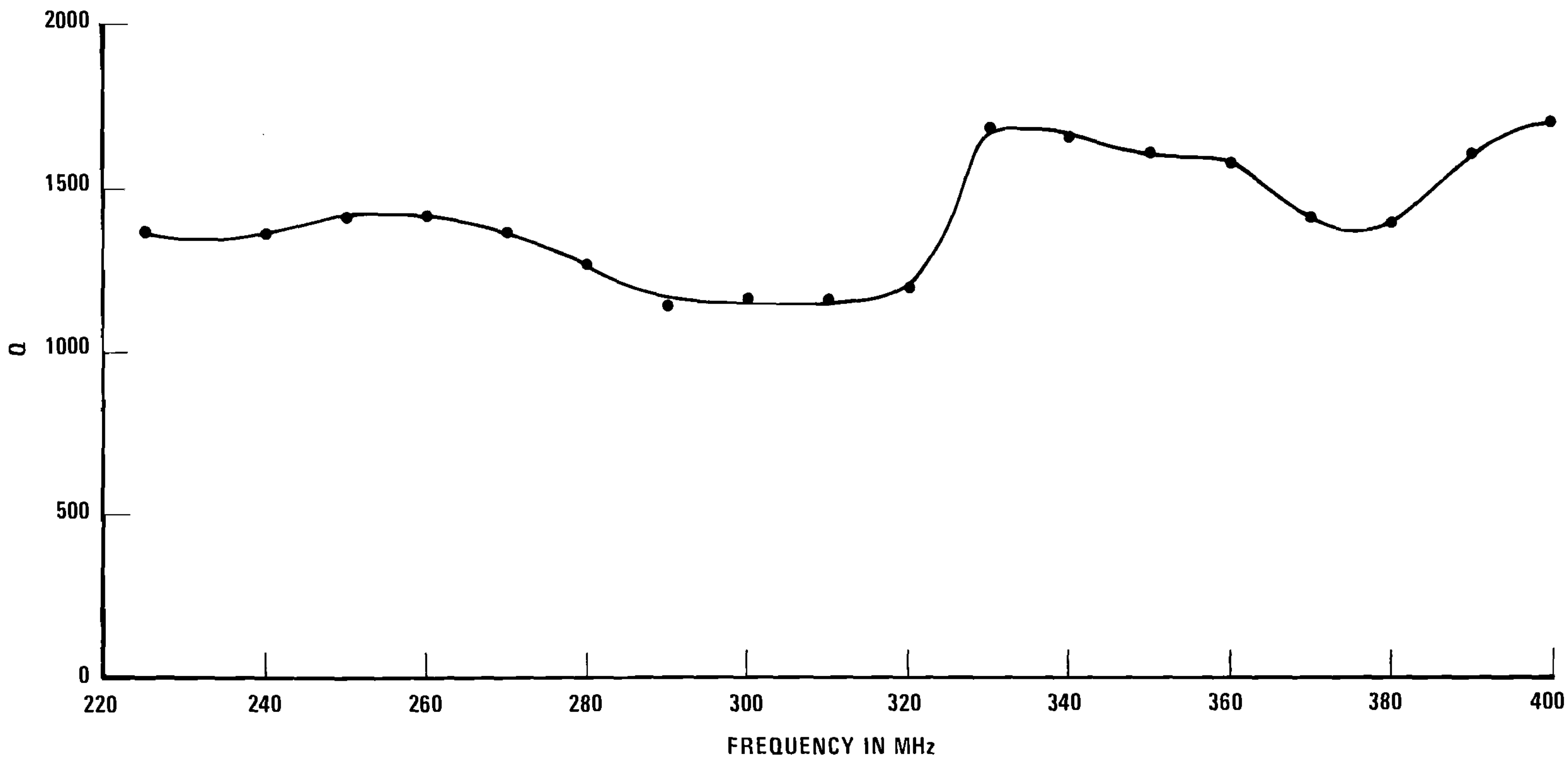


Figure 17. Effective Q of the Q Multiplier Filter as a Function of Frequency.

SECTION III

AM CANCELLATION FILTER

A. Introduction

Closely spaced unwanted signals can present a serious problem in communication receivers. If the level of the interfering signal is small, the interference may be manifested as an annoying beat frequency between the two signals which seriously degrades the intelligibility of the desired signal. In the case of a high level interfering signal, more serious problems often arise due to intermodulation product generation or complete saturation of the receiver RF amplifiers and mixers.

Conventional methods for overcoming these problems include the use of high Q bandpass filters to pass only the desired signal or the use of band reject filters to suppress the unwanted signal. Such methods are effective for signals adequately spaced in frequency. However, if the interfering signal is very close in frequency to the desired signal, then a conventional bandpass filter will not offer sufficient rejection to the unwanted signal while the band reject filter will excessively attenuate the desired signal.

A method of circumventing the limitations of conventional filters is to suppress the interference with a signal whose amplitude and phase are identical to that of the interfering signal. Subtracting this replica of the interfering signal from the sum of the desired and interfering signals results in cancellation of the interference leaving only the desired signal. When it is possible to obtain a sample of the interference directly as from a cosited transmitter through the use of a coaxial cable connection, then the phase and amplitude of the sample can be properly adjusted to produce cancellation of the interference. If a sample of the interfering signal is not available, it is then necessary to resort to the more complex approach of synthesizing a replica of the interfering signal.

A convenient method for synthesizing this cancellation signal is to generate an auxiliary signal which can be phase-locked to the interfering signal. This phase-lock technique is employed in the UHF AM Cancellation Filter to suppress both CW and amplitude modulated signals in the 200 to 400 MHz frequency range.

The UHF AM Cancellation Filter shown in Figure 18 is essentially a dual channel, double conversion, superheterodyne receiver with a 200-400 MHz cancellation oscillator and the necessary phase and amplitude control loops added. Basically, the system employs a common local oscillator to heterodyne separately the interfering signal and the cancellation signal to a convenient IF frequency. The two IF signals are generated in separate mixers and delivered to their respective IF amplifiers.

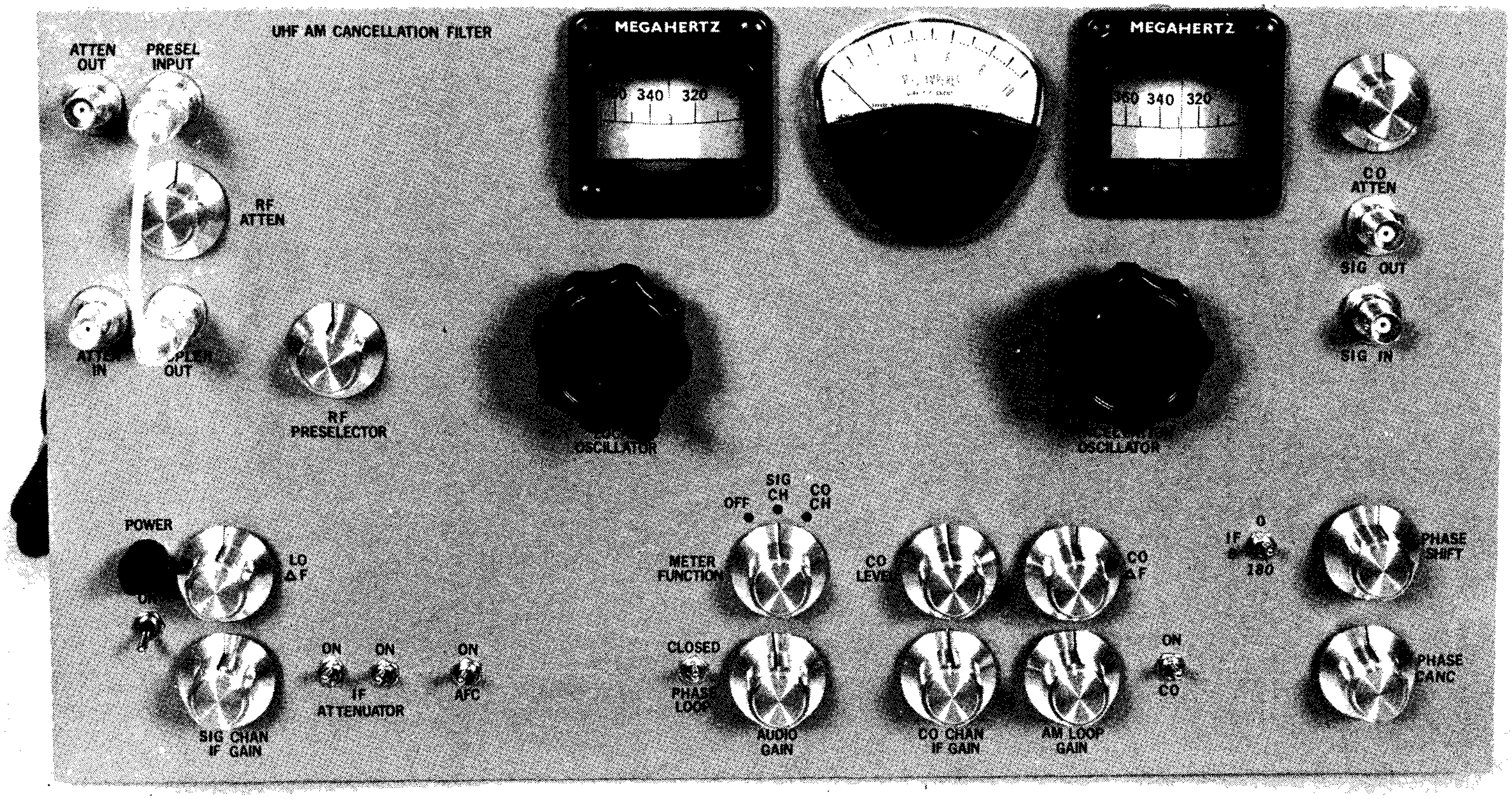


Figure 18. Front Panel View of the UHF AM Cancellation Filter.

The IF signals are then compared in a phase detector and an amplitude detector; the resulting error signals are used to control the frequency and amplitude, respectively, of the cancellation signal. The cancellation oscillator signal, being properly adjusted in frequency, phase and amplitude, is summed with the interference in a hybrid combiner to suppress the undesired signal.

B. Circuit Description

A block diagram of the complete UHF AM Cancellation Filter is given in Figure 19. Referring to the block diagram, the input signal which consists of both the desired and undesired signals is connected to the hybrid combiner and then the output of the hybrid is connected to the 10 dB directional coupler. A portion of the input signal is fed to the RF attenuator and RF preselector. The continuously variable RF attenuator is provided to prevent high level signals from overdriving the preselector. The signal is amplified by the transistor RF preselector and delivered to the first mixer in the signal channel. Concurrently, the low level output from the cancellation oscillator is delivered to the first mixer in the cancellation channel. Two isolated outputs from the first local oscillator are fed to each of the first mixers where the input signal and the cancellation signal are heterodyned to 31 MHz and delivered to their respective first IF amplifiers. The 31 MHz signals from each of the first IF amplifiers are delivered to the second mixers where they are heterodyned to a 7 MHz second IF by the crystal controlled second local oscillator.

The signal channel, 7 MHz IF output is delivered simultaneously to the phase detector, amplitude detector, envelope detector, IF limiter and to a rear-panel output connector. The envelope-detected signal provides the drive for the audio amplifier and the meter amplifier. The output of the IF limiter is coupled to a modified Foster-Sealey discriminator which provides the AFC voltage for the first local oscillator.

The cancellation channel, 7 MHz IF output is delivered to the variable phase shifter. A portion of this signal is also delivered to a rear panel output connector. The 7 MHz signal is also envelope detected to provide a level indicator. The voltage controlled variable phase shifter provides greater than 360 degrees phase adjustment and is used to set the loop phase to the value required for a stable operating condition. The output of the variable phase shifter is split into two quadrature signals for application to the phase and amplitude detectors.

The phase detector output is filtered by the lag network and applied to a varactor diode in the cancellation oscillator circuit. The phase error voltage adjusts the frequency of the cancellation oscillator to maintain phase-lock.

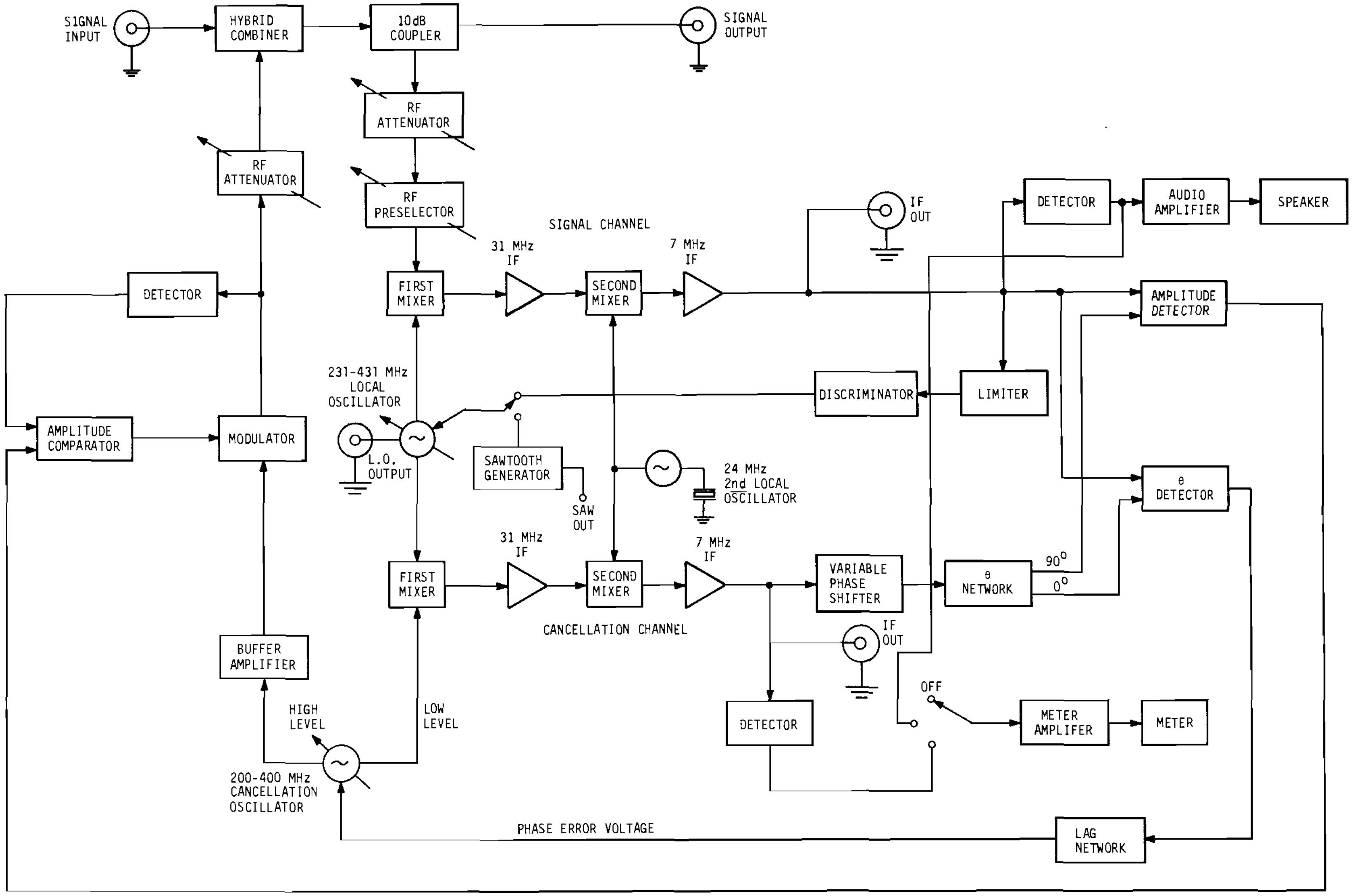


Figure 19. Block Diagram of the UHF AM Cancellation Filter.

When the cancellation oscillator is phase-locked to the interference, the error voltage produced by the amplitude detector represents the original modulation contained in the interfering signal. This signal is fed to the amplitude comparator whose output drives the PIN modulator. The high level output from the cancellation oscillator is delivered to the modulator through the buffer amplifier. The RF input impedance of the modulator varies as a function of the modulating signal which can introduce incidental FM into the cancellation signal because of the variable loading of the cancellation oscillator. The broadband buffer amplifier provides sufficient isolation between the oscillator and the modulator to prevent this incidential FM of the cancellation signal. A portion of the modulated cancellation signal is detected and compared with the error signal derived from the amplitude detector. This feedback modulator insures that the modulation of the cancellation signal will be a faithful reproduction of the error signal as obtained from the amplitude detector.

The cancellation signal, now properly adjusted in frequency, phase and amplitude, is summed with the desired and undesired signal to produce cancellation of the undesired interfering signal. It should be noted that the actual RF input to the cancellation filter, the -10 dB port of the directional coupler, follows the hybrid combiner. With this configuration, the cancellation filter operates on the residual of the interfering signal as a closed loop system. This technique also prevents the RF section of the cancellation filter from being overloaded by the large interfering signal once phase-lock is established and suppression is obtained.

Since the frequencies of the cancellation signal and the interfering signal are the same in a phase-locked condition, it is important that the center frequency response of the two IF channels be closely matched. A low frequency sawtooth generator is incorporated into the system to aid in the alignment of the two IF channels. For alignment, the sawtooth sweep voltage is fed to the varactor in the first local oscillator and an external RF signal is delivered to each of the first mixers. Alignment is then accomplished by matching the swept responses of the two IF channels.

C. Cancellation Capabilities

The ability of the UHF AM Cancellation Filter to suppress AM and CW interference is demonstrated by the following examples. The spectrum presentation of Figure 20A shows a large interfering signal that is 50 per cent amplitude modulated at 1 kHz, which almost completely obscures the low level desired signal which is located 100 kHz from the interference. When the two signals are processed by the cancellation filter, the relative levels are as shown in the photograph of Figure 20B. The interfering signal has been suppressed almost 40 dB and the desired signal is no longer obscured by the interfering signal. Although the interfering signal is still present, the level has been sufficiently

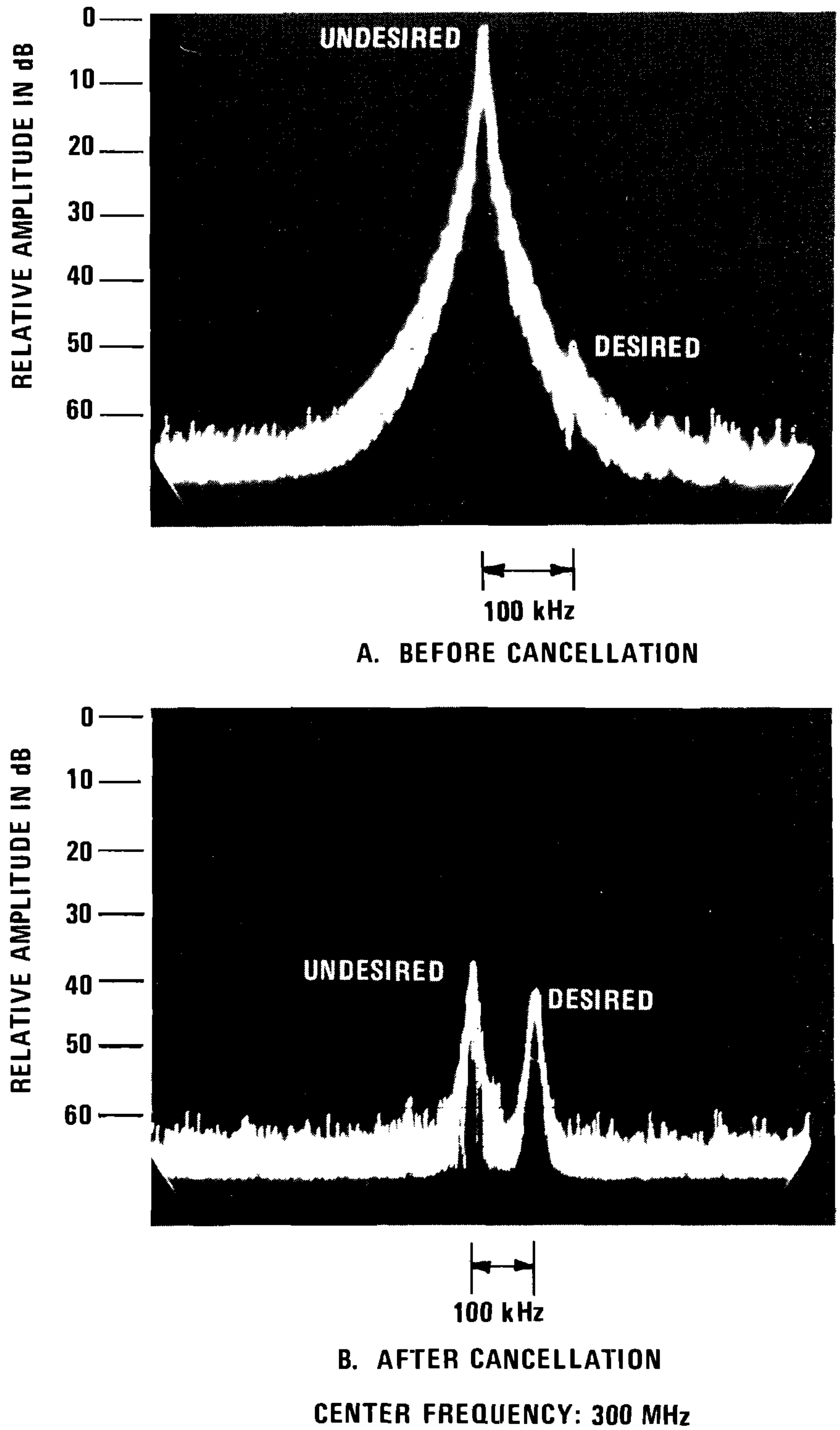


Figure 20. Spectrum Analyzer Displays Which Show Cancellation of an AM Signal With the AM Cancellation Filter.

reduced such that it would probably not overload a receiver front end. In this particular case, the selectivity of the receiver would, in general, provide the necessary additional rejection of the undesired signal.

In the spectrum display shown in the photograph of Figure 21A, the low level desired signal is almost concealed by a large CW interfering signal which is spaced in frequency only 30 kHz from the desired signal. In the spectrum presentation of Figure 21B, the interfering signal has been reduced approximately 50 dB and the desired signal is no longer hidden by the interfering signal.

As shown by these spectrum displays, the UHF AM Cancellation Filter is capable of providing 35 to 40 dB suppression of an interfering AM signal and 40 to 50 dB for CW interference. This difference can be attributed to the fact that for CW interference, the cancellation signal is required to track only the slow frequency and phase variations that occur between the interfering and cancellation signals. For an AM interfering signal, however, the cancellation signal must not only track the frequency variations but must also accurately reproduce the AM signal and track the incidental phase modulation that is generally present in amplitude modulated signals.

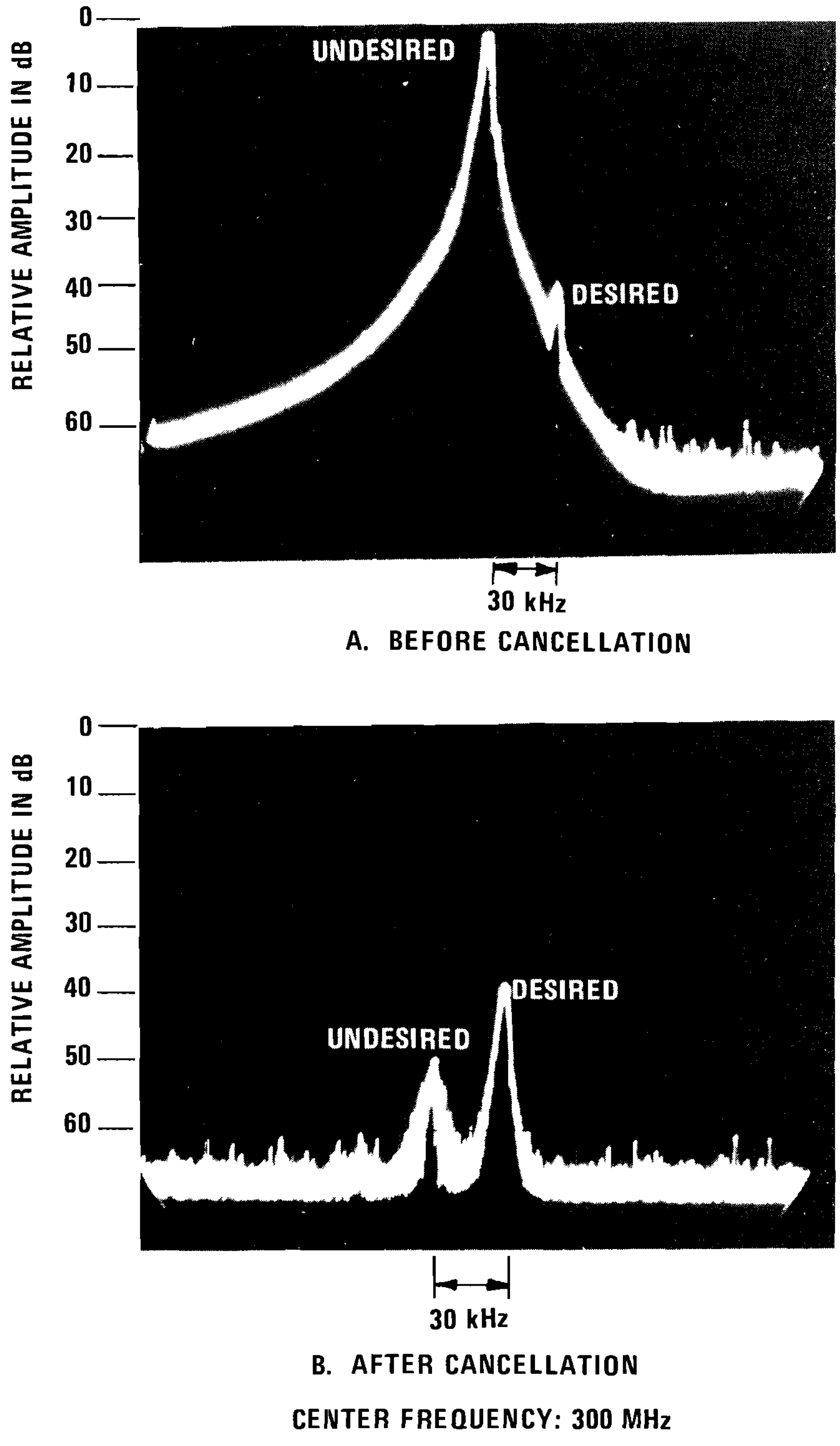


Figure 21. Spectrum Analyzers Displays Which Show the CW Suppression Capabilities of the AM Cancellation Filter.

SECTION IV

BROADBAND LINEAR AMPLIFIERS

A. General Considerations

The extension of the dynamic range of active filters is closely related to an improvement in their linearity characteristics and power handling capabilities. The maximum power that can be handled is determined by the dissipation characteristics of the active device employed. If distortion in the signal path is to be minimized, the device must operate in a linear mode well below its usual saturation power level. Hence, the maximum power level that the filter can handle is determined by the dissipation and saturation characteristics of the active elements. The total dynamic range is the total voltage swing that the device can handle between its saturation level and its residual noise level. The dynamic range can be extended by reducing the residual noise level and raising the saturated power level. The residual noise level can be lowered by the use of active elements of lower noise figures in circuit configurations conducive to low noise operation. A straightforward approach to increasing the saturated output power level is to utilize active elements capable of high power dissipation. Recent advances in solid state technology have resulted in transistors capable of delivering several watts in the UHF region.

Figure 22 illustrates the manner in which the actual transfer characteristic of a typical active element deviates from the ideal behavior. The characteristics of a device with improved linearity is also illustrated. In the region between the residual noise level and the saturation level of the device, the transfer characteristic will exhibit some deviation from a straight-line behavior. This nonlinear behavior determines the performance of the device in a multiple signal environment. Cross modulation, intermodulation and waveform distortion are produced by the nonlinearities. Consequently, it is desirable to maximize the linearity of the transfer function over as wide a dynamic range as possible.

For the ideal transfer characteristic shown in Figure 22, the output voltage is a constant multiple of the input voltage, that is

$$e_o = a_1 e \quad . \tag{14}$$

For the practical case, however, the transfer characteristic is not linear, and is more appropriately represented by

$$e_o = a_1 e + \sum_{n=2}^{\infty} a_n e^n \quad , \tag{15}$$

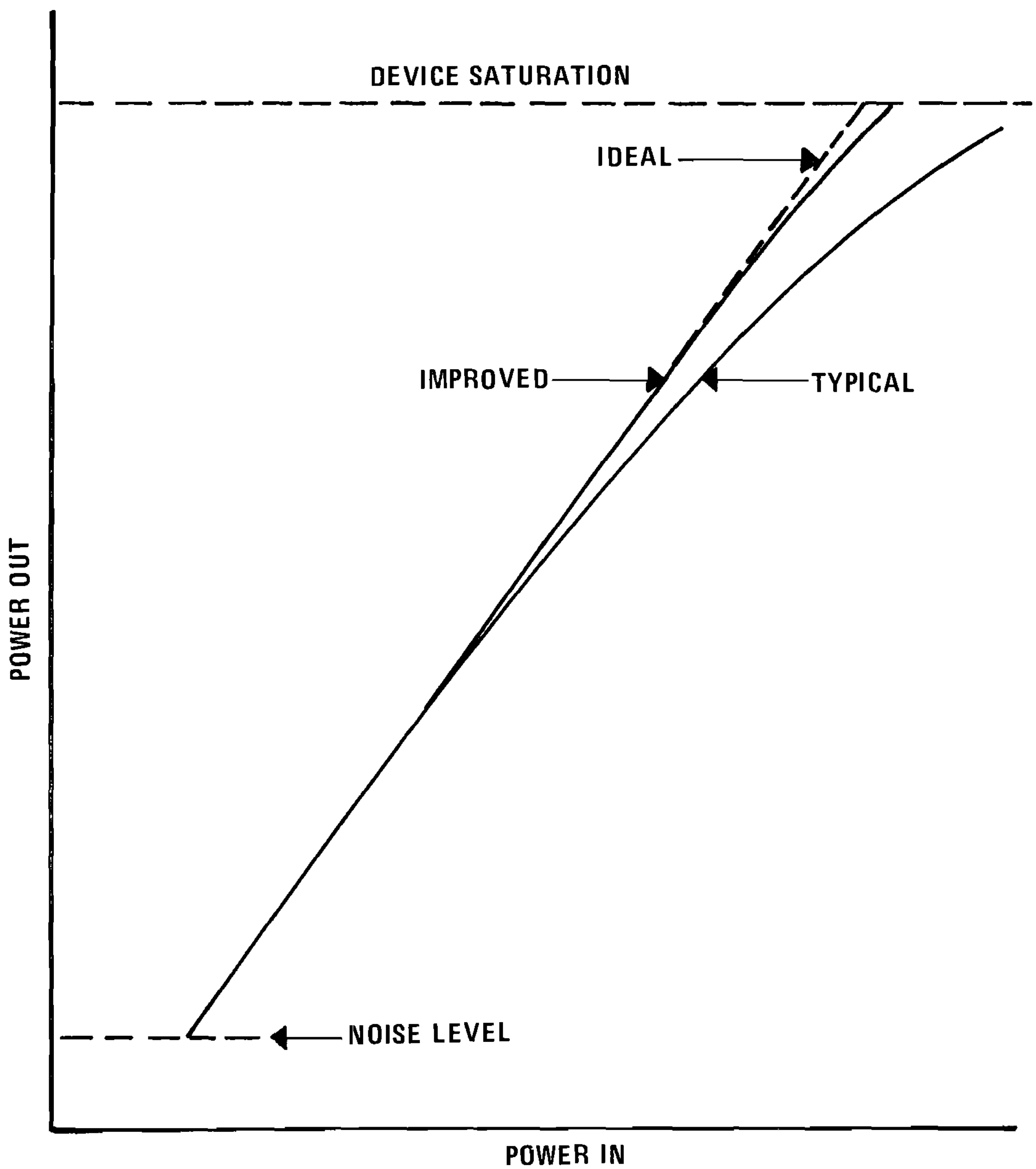


Figure 22. Comparison of Typical Amplifier Transfer Characteristics.

where e = the effective input voltage,

e_o = the output voltage, and

a_n = power series coefficients whose values are dependent upon the characteristics of the nonlinearity.

Thus, in addition to the desired output, a_1e, distortion products will be present caused by the higher order terms a_2e^2, a_3e^3, etc.

Negative feedback has long been recognized as an effective technique for reducing nonlinear distortion products in amplifier circuits. Consider the feedback network of Figure 23, where e is the applied voltage. The effective input voltage is

$$e_i = e - \beta\, e_o \quad , \tag{16}$$

assuming negative feedback, β being the fraction of the output voltage that is fed back to the input.

Substituting (15) into (16):

$$e_i = e - \beta\, a_1 e_i - \beta\, a_2 e_i^2 - \beta\, a_3 e_i^3 - \cdots \quad , \tag{17}$$

or

$$e_i + \beta\, a_1 e_i = e - \beta\, a_2 e_i^2 - \beta\, a_3 e_i^3 - \cdots \quad . \tag{18}$$

Then,

$$e_i = \frac{e}{1 + a_1\beta} - \frac{a_2\beta e_i^2}{1 + a_1\beta} - \frac{a_3\beta e_i^3}{1 + a_1\beta} - \cdots \quad . \tag{19}$$

Panter [10] provides a technique for obtaining the output voltage e_o in terms of the applied voltage e. From the expression for e_i in (19), he proceeds to obtain the basic feedback equation

$$e_o = a_1 e + \frac{a_2 e^2}{1 + a_1\beta} + \left[\frac{a_3}{1 + a_1\beta} - \frac{2a_2^2\beta}{(1 + a_1\beta)^2}\right] e^3 + \cdots \quad , \tag{20}$$

where the input voltage e has been increased by the factor $(1 + a_1\beta)$ to restore the output to its level without feedback.

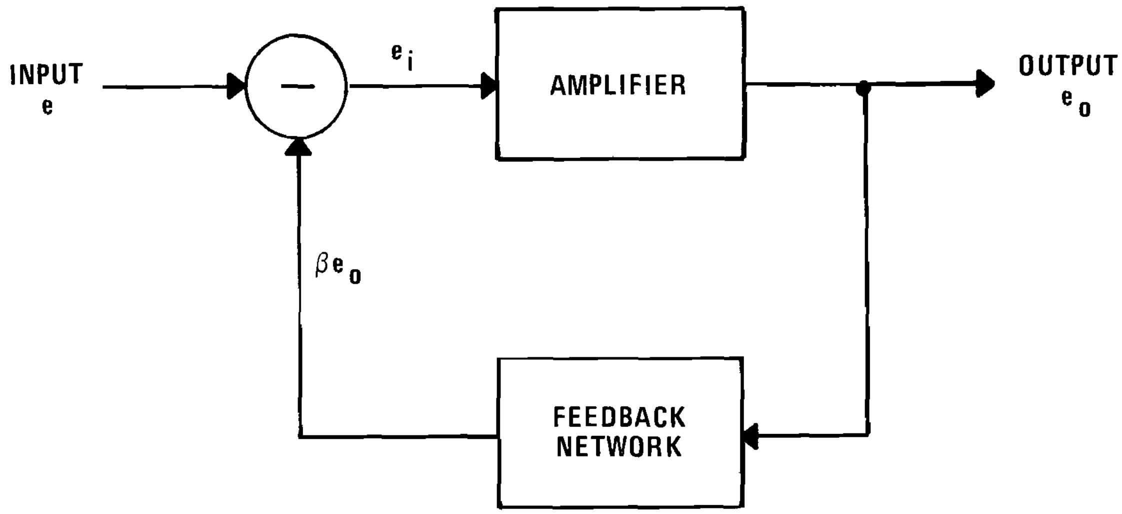


Figure 23. Diagram of a Basic Negative Feedback System.

The form of equation (20) makes it difficult to evaluate the merits of negative feedback in reducing distortion products. The equation is usually approximated by assuming that $a_1\beta > 1$ and that the coefficient a_1 is much greater than the coefficients of the higher order terms. Under these assumptions, equation (20) can be expressed as

$$e_o = a_1 e + \frac{a_2}{1 + a_1\beta} e^2 + \frac{a_3}{1 + a_1\beta} e^3 + \ldots \quad , \tag{21}$$

or

$$e_o = a_1 e + \frac{1}{1 + a_1\beta} \sum_{n=2}^{\infty} a_n e^n \quad . \tag{22}$$

Equation (22) shows that the coefficients of the higher order terms in the nonlinear transfer characteristic have been reduced in amplitude by the factor $\frac{1}{1 + a_1\beta}$; hence harmonics or distortion products generated by these higher order terms will be reduced by this factor.

Another method of improving amplifier performance is through the use of power division. Rather than using a single amplifier, suppose the signal to be amplified is split into k paths with a k-way power divider as shown in Figure 24. Each of the k paths contains an amplifier to provide the desired gain. The k outputs of the amplifiers are then combined using another k-way signal divider.

Several advantages result from the power division technique. First, a high level signal may be divided into a number of lower level signals which can be handled with amplifiers of lower power rating. Second, this technique allows the voltage swing at the input to the amplifiers to be restricted to a more linear portion of the transfer characteristics.

The effect of power division in reducing distortion products can be illustrated from equation (15), which is repeated below.

$$e_o = a_1 e + \sum_{n=2}^{\infty} a_n e^n \quad . \tag{23}$$

Suppose that the input signal, e, is divided into k paths, each containing an amplifier with a transfer characteristic represented by equation (23). The signal power in each path would thus be proportional to e^2/k and each amplifier output would be represented by

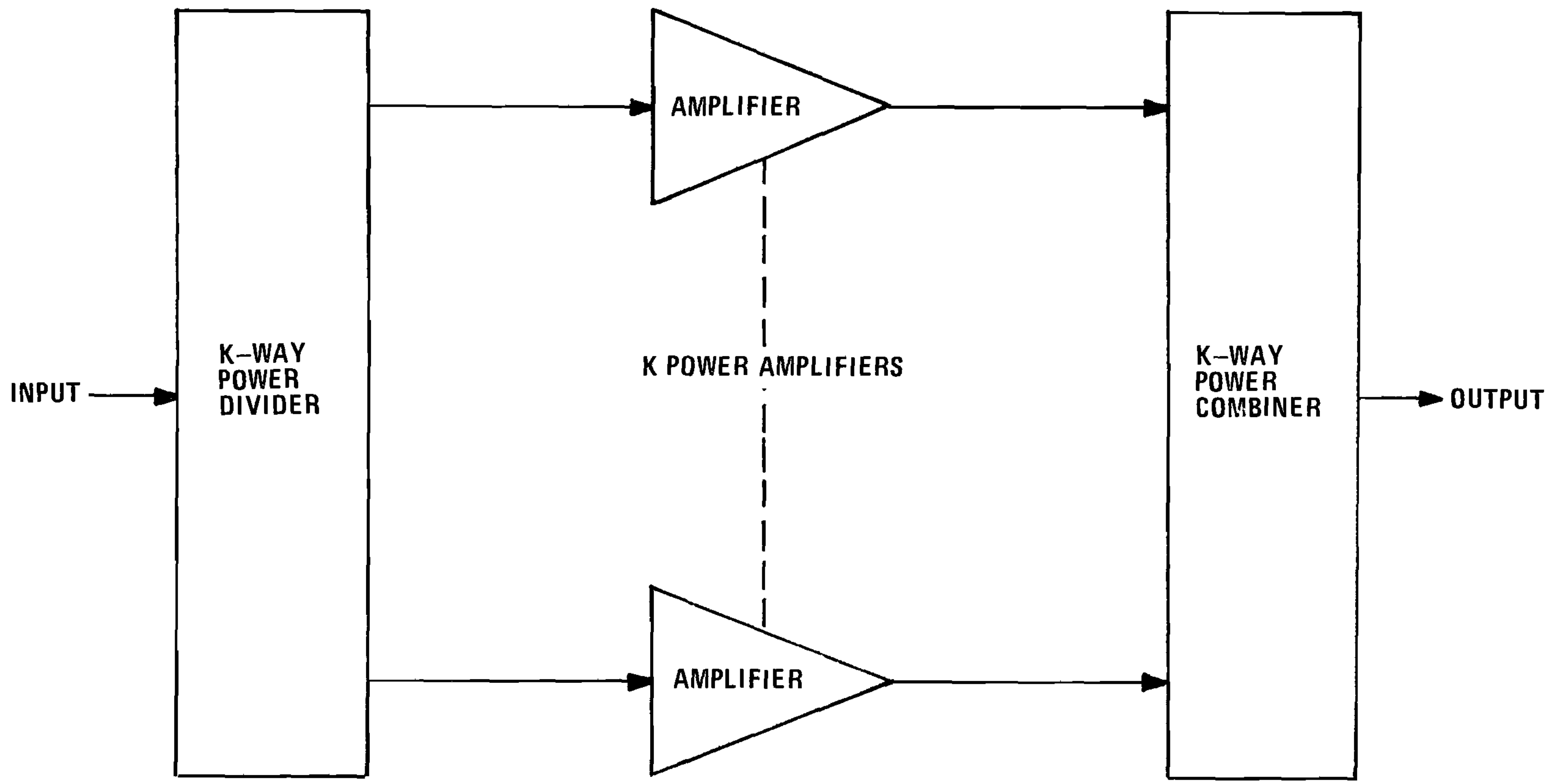


Figure 24. Illustration of Power Sharing Mode of Operation.

$$e_{ok} = a_1 \frac{e}{\sqrt{k}} + \sum_{n=2}^{\infty} a_n \left(\frac{e}{\sqrt{k}}\right)^n \quad . \tag{24}$$

To recover the desired signal, the signal power in each individual path must be summed. But the power in each path is proportional to

$$P_{ok} \propto (e_{ok})^2 = \left[a_1 \frac{e}{\sqrt{k}} + \sum_{n=2}^{\infty} a_n \left(\frac{e}{\sqrt{k}}\right)^n\right]^2 \quad . \tag{25}$$

Summing for k paths,

$$\sum^{k} P_{ok} = k \left[a_1 \frac{e}{\sqrt{k}} + \sum_{n=2}^{\infty} a_n \left(\frac{e}{\sqrt{k}}\right)^n\right]^2 \quad , \tag{26}$$

and the output voltage would thus be

$$e_o = \sqrt{k} \left[a_1 \frac{e}{\sqrt{k}} + \sum_{n=2}^{\infty} a_n \left(\frac{e}{\sqrt{k}}\right)^n\right] \quad . \tag{27}$$

or

$$e_o = a_1 e + \sqrt{k} \sum_{n=2}^{\infty} a_n \left(\frac{e}{\sqrt{k}}\right)^n \quad . \tag{28}$$

Equation (28) may also be expressed as

$$e_o = a_1 e + \frac{a_2 e^2}{(k)^{\frac{1}{2}}} + \frac{a_3 e^3}{k} + \frac{a_4 e^4}{(k)^{3/2}} + \ldots + \frac{a_n e^n}{(k)^{\frac{n-1}{2}}} \quad , \tag{29}$$

which illustrates the reduction in amplitude that will occur for distortion products generated by the higher order terms.

As an example of harmonic reduction that can be achieved through power division, consider the case where the amplifier input signal is

$$e = V \cos \omega t \quad . \tag{30}$$

Expanding this input in equation (29) yields harmonic terms of the form $C_n \cos n\omega t$, where the harmonic coefficient, C_n, is in series form. If C_n is approximated by neglecting contributions from higher order terms in the expansion (i.e., if C_n is derived only from the lowest order term in equation (29) which generates the nth harmonic), the amplifier output from equation (29) is

$$e_o = a_1 V \cos \omega t + \frac{a_2 V^2}{2(k)^{\frac{1}{2}}} \cos 2\omega t + \frac{a_3 V^3}{4k} \cos 3\omega t + \frac{a_4 V^4}{8(k)^{3/2}} \cos 4\omega t + \ldots \tag{31}$$

Without power division, the output would be represented by an expansion of equation (30) in equation (15), which would yield

$$e_o = a_1 V \cos \omega t + \frac{a_2 V^2}{2} \cos 2\omega t + \frac{a_3 V^3}{4} \cos 3\omega t + \frac{a_4 V^4}{8} \cos 4\omega t + \ldots \quad . \tag{32}$$

A comparison of equations (31) and (32) reveals that the use of power division reduces the second harmonic voltage by $1/\sqrt{k}$, the third harmonic voltage by $1/k$, etc. In general, the nth harmonic voltage will be reduced by the factor $\left[\frac{1}{[k]^{\frac{n-1}{2}}}\right]$, where $n \geq 2$. The nth harmonic power would thus be reduced by $\left[\frac{1}{[k]^{(n-1)}}\right]$.

B. Experimental Results

The effectiveness of negative feedback in reducing distortion is shown by equation (20). Equation (19) shows, however, that reduced fundamental gain must be tolerated to obtain reduction of distortion products. For example, broadband negative feedback is often realized with an unbypassed series emitter resistance. Since this resistance is a part of the ac path, it directly lowers the gain of the circuit.

A common emitter configuration utilizing a 2N3866 transistor was evaluated for harmonic generation as a function of power output level with two different values of emitter resistance. Figure 25 shows that the level of the second harmonic with a 47 ohm resistance was typically 5 dB lower than the level with a 10 ohm resistance. Below saturation, the third harmonic levels fall closely together for both resistance values. With the 10 ohm resistance, the third harmonic levels show a dramatic upswing above +20 dBm.

Since the common base configuration is often recommended as a broad-band amplifier in the VHF and UHF ranges, a common base 2N3866 amplifier was evaluated for its harmonic generation characteristics. The curves shown in Figure 26 illustrate that high harmonic levels were observed in the common base amplifier. Typically the second harmonic levels appear to be approximately 30 dB higher in the common base amplifier than in the common emitter amplifier. The erratic nature of the third harmonic variation makes a relative comparison difficult; however, over the range of power levels tested, the common emitter amplifier demonstrates lower third harmonic generation. On the basis of these measurements, further development emphasized the use of the common emitter configuration.

The 2N3866 represents a class of transistors whose collector is tied directly to the case. In any configuration except common collector, the case must be left floating, i.e., the collector junction is effectively RF exposed and is very susceptible to circuit parasitics. In the common emitter amplifier, the case cannot be thermally connected to the chassis without destroying the frequency response due to the shunt capacity of the heat sink. Consequently, high power operation is restricted because of the limited heat dissipation available with the 2N3866 transistor.

Good thermal conductivity with electrical isolation between terminals and case is obtained with stud-mounted transistors such as the 2N5090 and 2N3375. Both transistors exhibit RF characteristics comparable to the 2N3866 and are capable of dissipating greater than 5 watts. Although the published data indicate that the two transistors are quite similar, experimentally, the 2N3375 exhibited less stability and required careful adjustment of the dc bias to obtain stable operation. Several amplifiers were constructed with both the 2N5090 and 2N3375 and, overall, the 2N5090 exhibited the more desirable characteristics of improved stability, greater bandwidth, and less complex tuning for a flat frequency response.

The circuit configuration shown in Figure 27 is a good basic single-stage amplifier in that it exhibits a flat gain response as shown by Figure 28, shows relatively low pertubation of the gain characteristics, and maintains stability when cascaded with other similar stages. Two of the basic amplifiers were combined in the push-pull configuration shown in Figure 29 to produce a building-block amplifier which was used to evaluate the effectiveness of power sharing techniques to obtain improved linearity. Two of these building-block amplifiers were combined in the

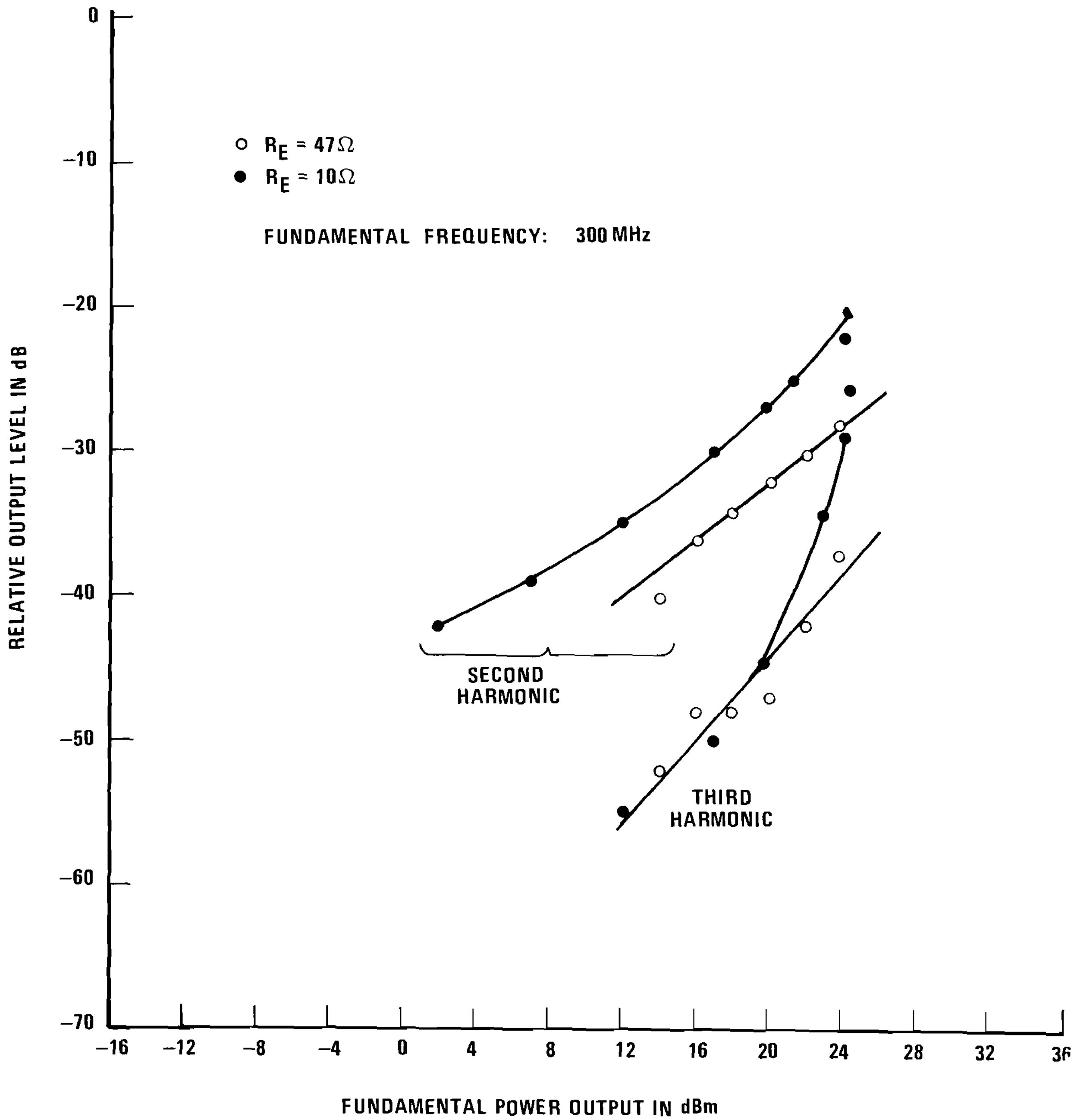


Figure 25. Harmonic Generation Levels for Two Values of Emitter Resistances.

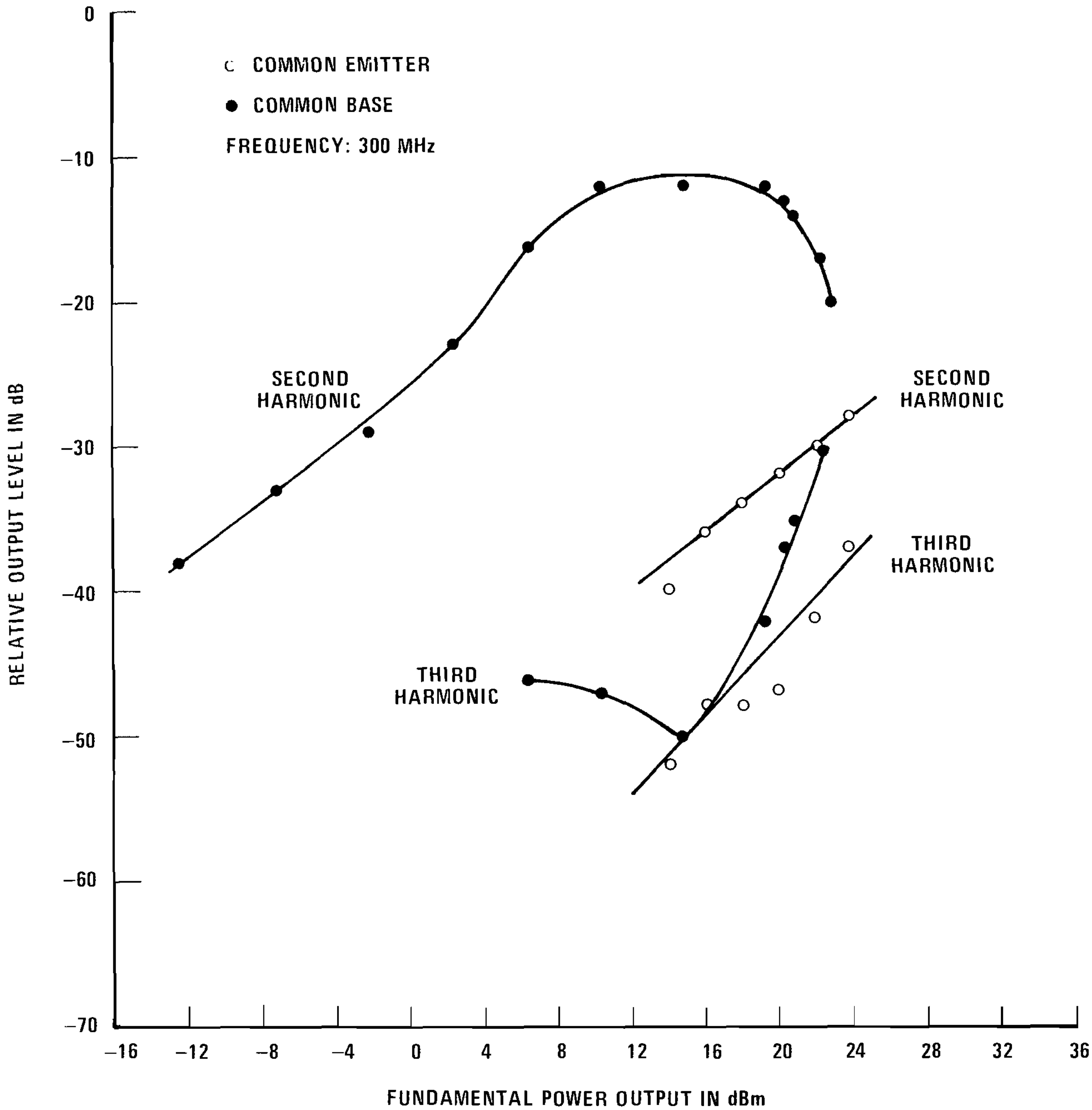
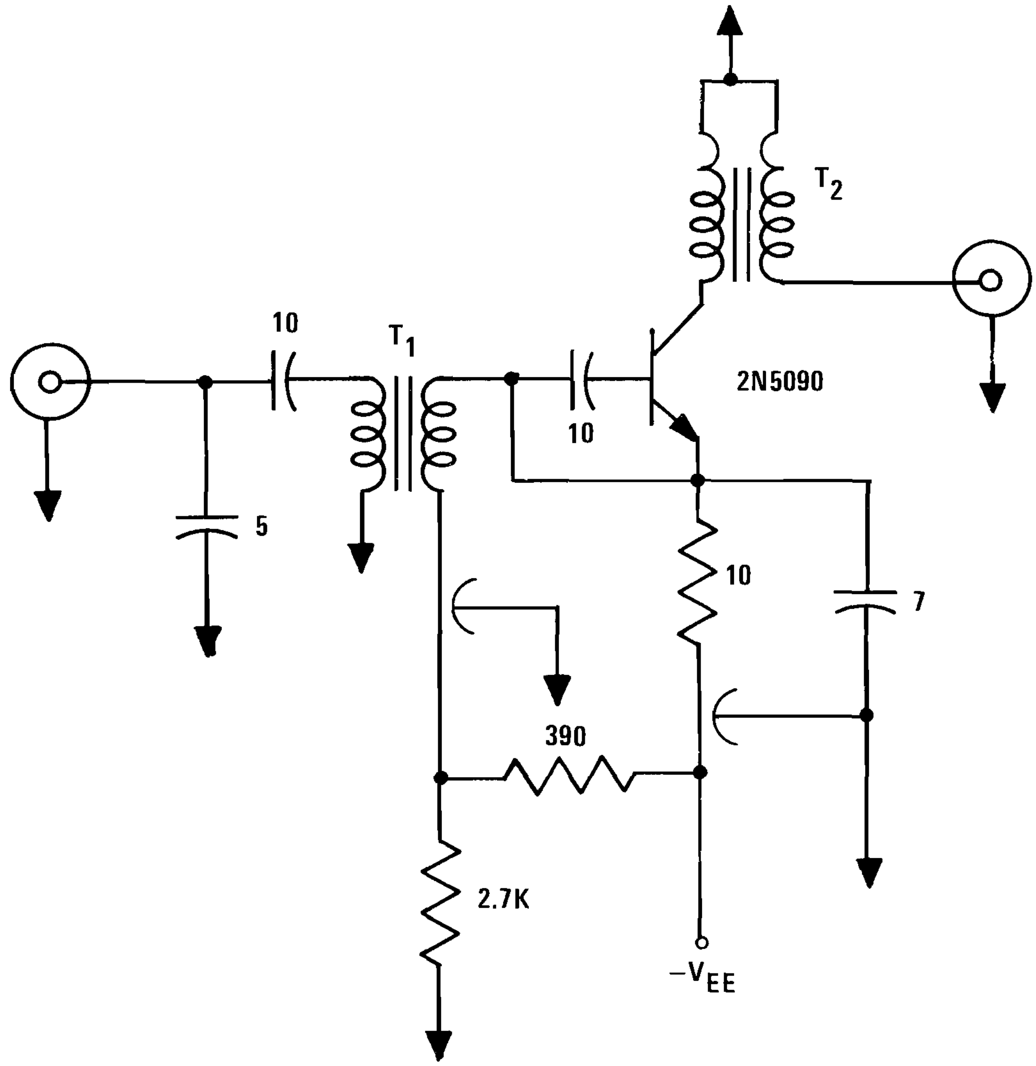


Figure 26. A Comparison of the Harmonic Levels Generated by a Common Base Amplifier and by a Common Emitter Amplifier.



T_1, T_2: 1:1 BROADBAND TRANSFORMERS

Figure 27. Schematic Diagram of a Single Stage Broadband Amplifier.

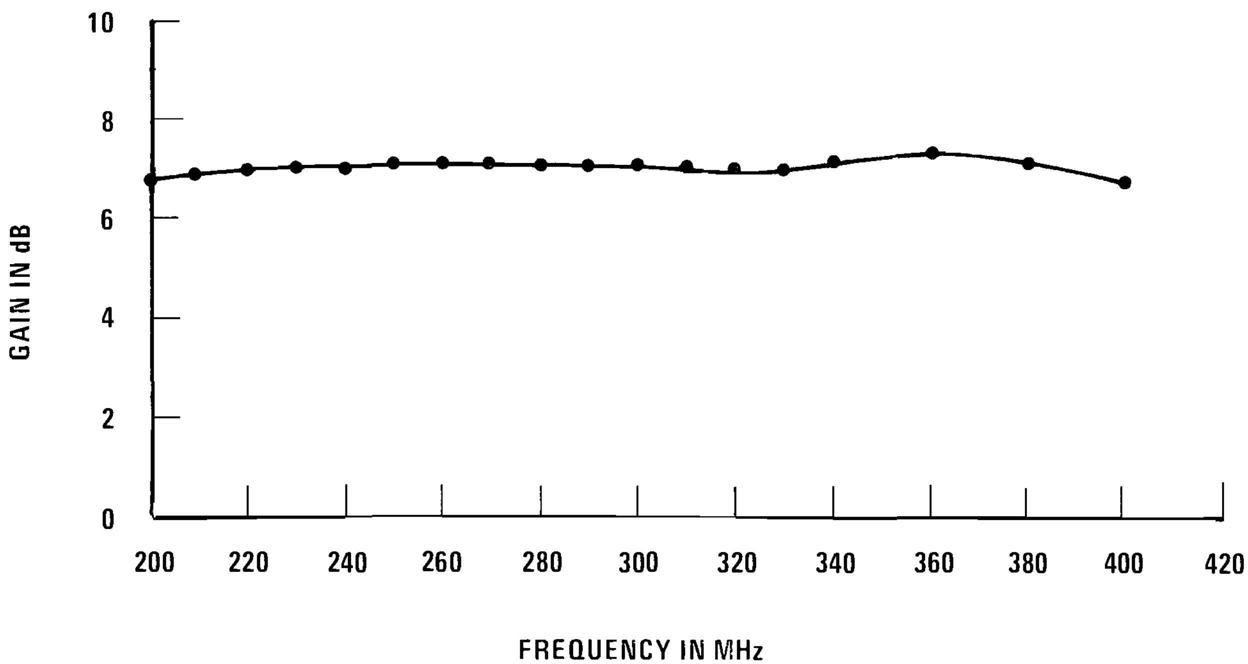


Figure 28. Gain Characteristics of the Single Stage Amplifier.

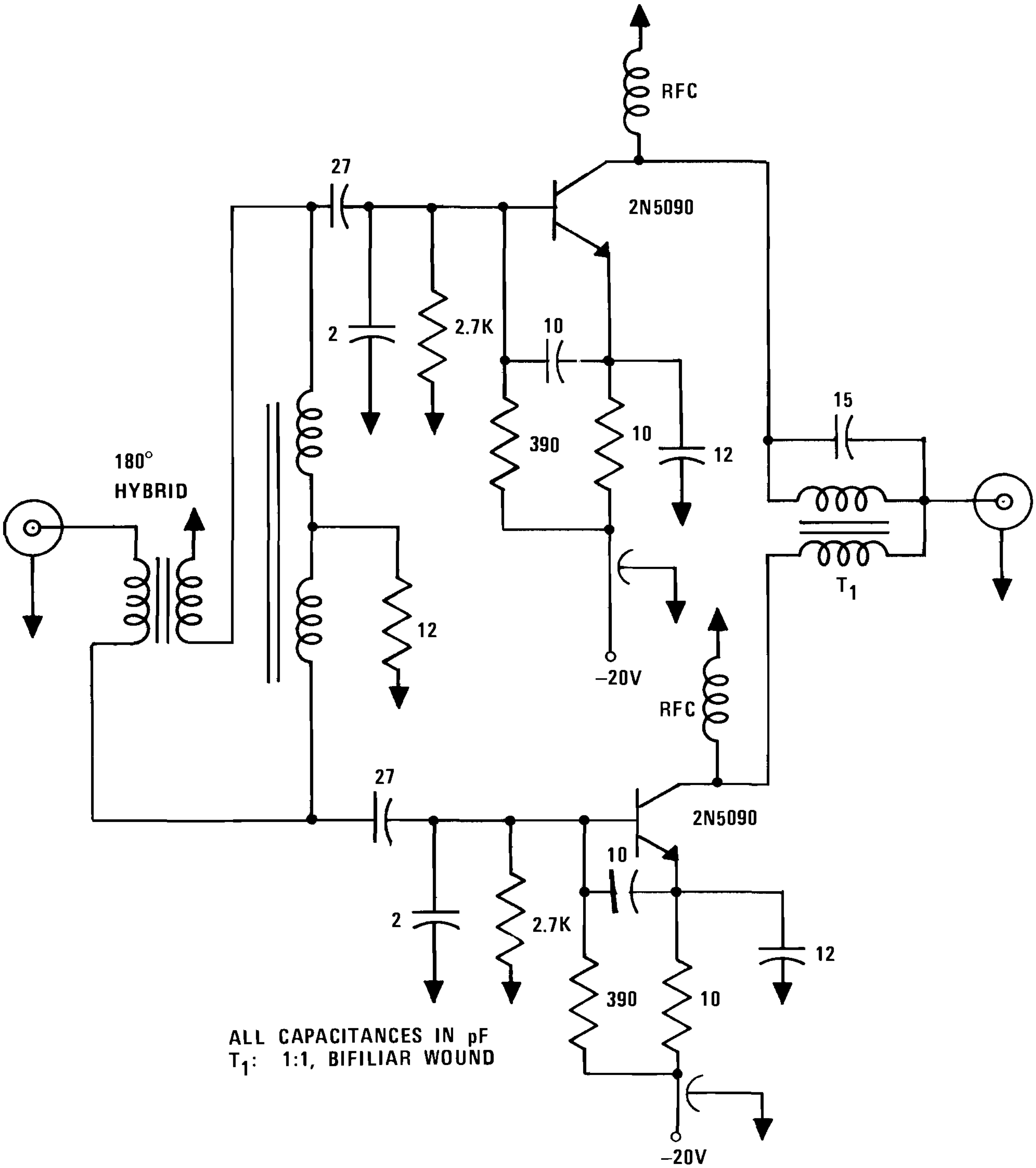


Figure 29. Basic Building-Block Amplifier Consisting of Two Parallel Stages.

push-pull arrangement shown in Figure 30 which was in turn combined in parallel in another similar arrangement to produce an amplifier consisting of eight basic transistor amplifiers in parallel.

In the basic amplifier, a compromise between improved linearity and reduced gain is achieved by using a 10 ohm unbypassed emitter resistor to supply broadband negative feedback. With this resistance, the basic amplifier typically exhibited 6 dB gain over the 200 to 400 MHz range.

Parallel amplifiers can be operated either in the push-pull mode or in the push-push mode. For push-pull operation the amplifiers are driven out-of-phase and summed out-of-phase whereas in the push-push mode of driving signals are in phase and summation is provided by the in-phase ports of the hybrid. The relative levels of the second harmonic generated in each mode are illustrated in Figure 31 in comparison with the levels generated in a single stage amplifier. Push-push operation of paralleled amplifiers achieves a 6 dB reduction in the second harmonic level over the single amplifier. Push-pull operation provides an additional 5 dB of second harmonic reduction for output levels less than +20 dBm. The third harmonic level was about the same for either parallel mode.

The levels of second and third harmonic generation for a single stage amplifier and for two, four and eight push-pull stages are shown in Figure 32. The level of second harmonic generation for four stages in parallel is approximately 10 dB less than the levels generated in a single stage amplifier. Eight parallel stages exhibit an additional 10 dB reduction. Approximately 20 dB reduction in the third harmonic level is achieved in going from a single stage amplifier to eight parallel stages. The eight-stage amplifier shows a second harmonic level of -42 dB and a third harmonic level of -58 dB at a one-watt output level.

This amplifier development program has shown the improvement in linearity which may be expected from the application of negative feedback and power sharing techniques to UHF, broadband transistor power amplifiers. Negative feedback in the nature of unbypassed emitter resistance is quite effective; however, a compromise between linearity improvement and gain reduction must be made. As expected, significant reduction in the level of harmonics is achieved by the use of parallel broadband stages. Both second and third harmonic levels are reduced by parallel operation. The data also indicate that the push-pull mode is preferred because this mode provides greater rejection to second harmonic generation than the push-push mode. As expected, these linear amplifiers are not very efficient. For example, to provide the one-watt fundamental output with the second harmonic down 42 dB and the third harmonic down 58 dB, ten watts of dc power were required for an efficiency of only 10 per cent.

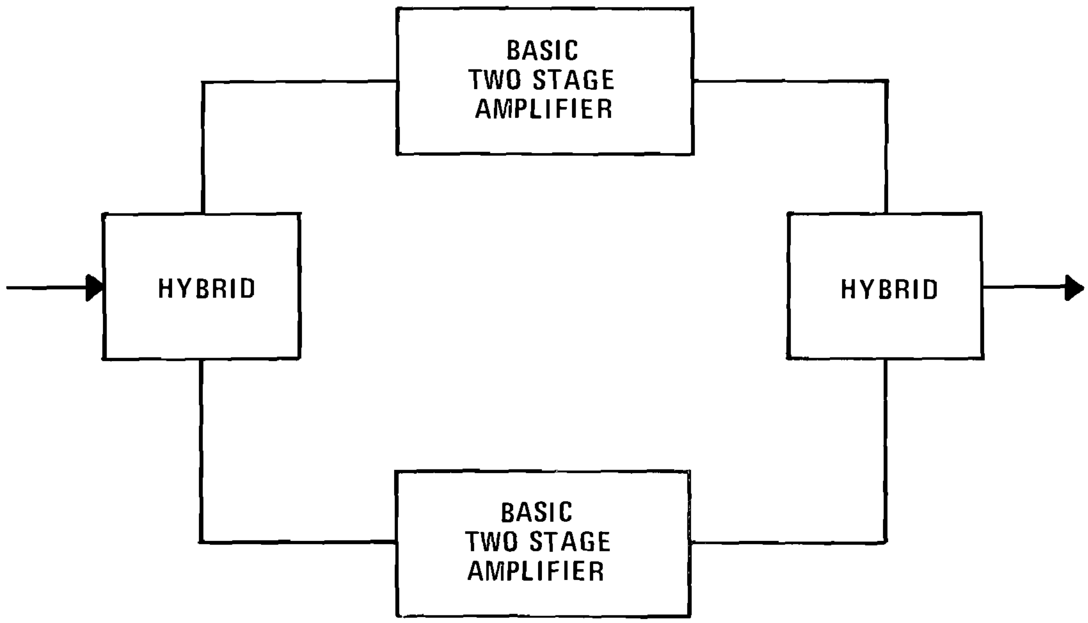


Figure 30. Block Diagram of Paralleled Amplifier Arrangement for Push-Pull or Push-Push Operation.

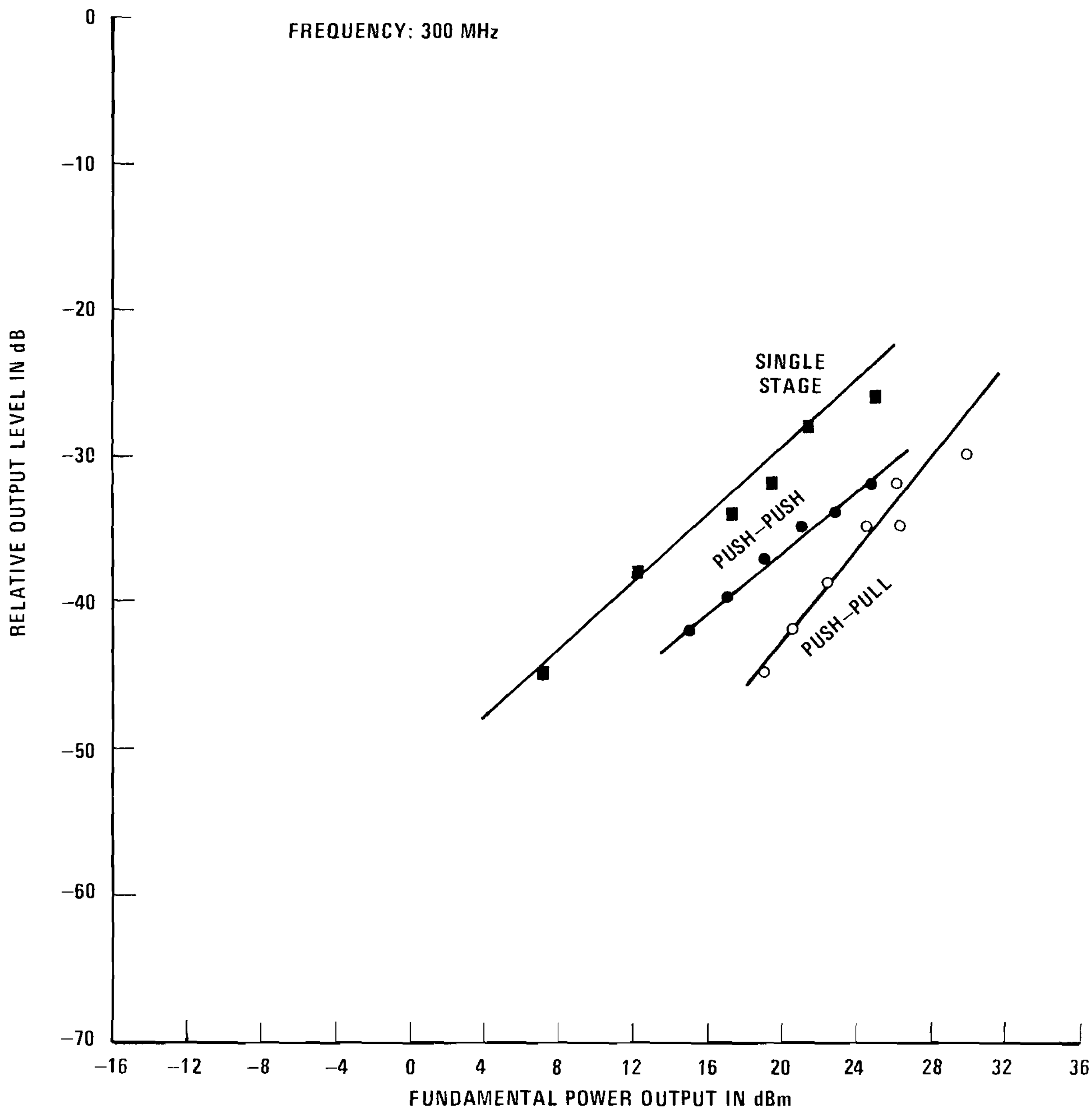


Figure 31. Second Harmonic Generation Characteristics of One-Stage, Two-Stage and Four-Stage Amplifiers.

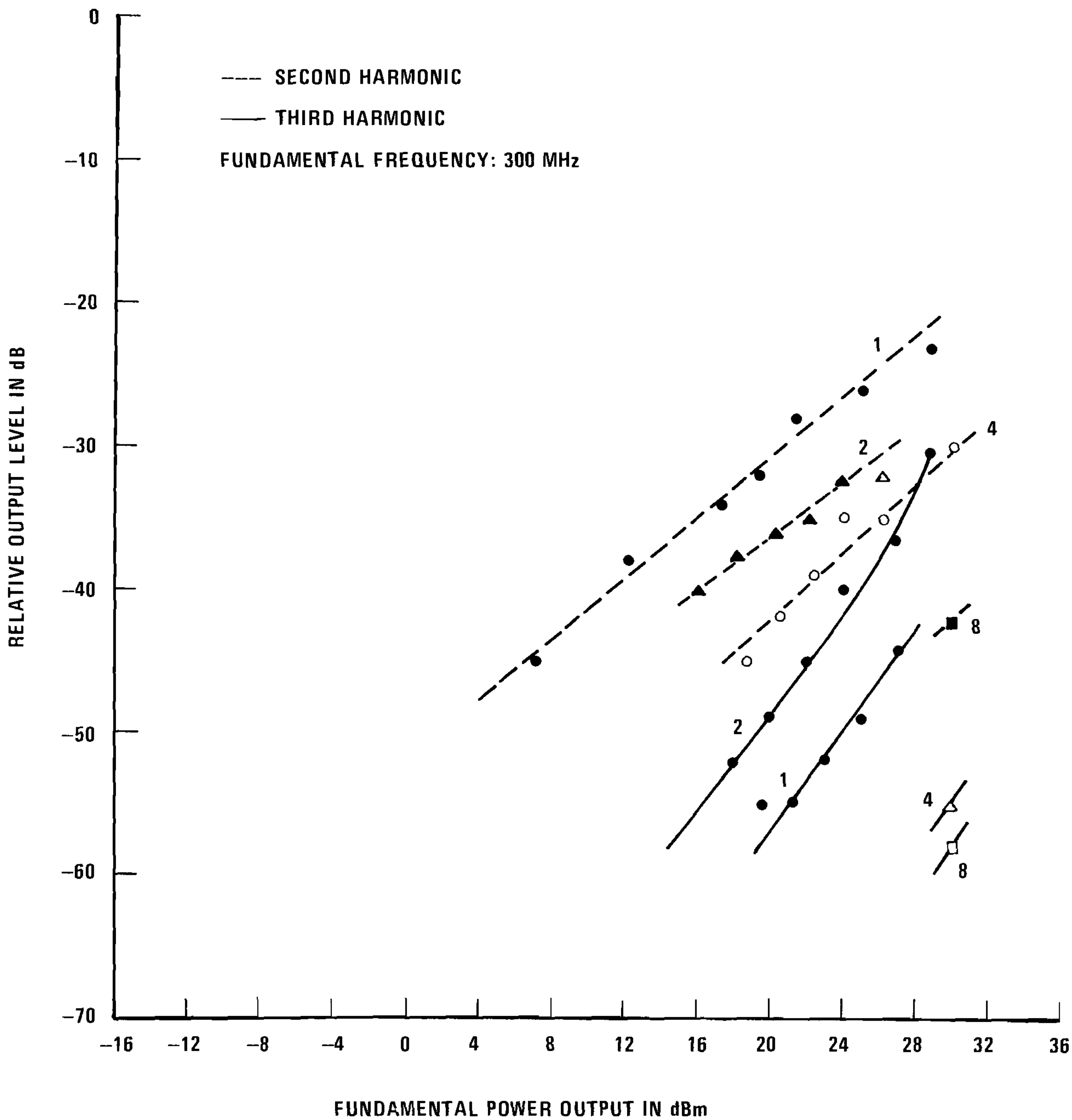


Figure 32. Harmonic Generation Characteristics of Various Amplifier Configurations.

SECTION V

CONCLUSIONS

The instabilities normally associated with high orders of multiplication can be avoided through the use of multiple feedback loops. In this way, extremely high Q's can be obtained from small sized resonators of moderate Q. Although active Q multiplication improves the relative stop band attenuation of the resonator, the rate of attenuation rolloff is still determined by the number of resonator stages. If steep skirt characteristics are required, multiple stages in series are necessary. The advantages presented by cascaded stages of Q multiplication are a narrow bandwidth combined with a high skirt selectivity.

It was shown analytically and experimentally that a negative resistance function which is effective over a broad range of frequencies can be realized. This negative resistance can be used to enhance the Q of coaxial cavities and other passive resonators in the 200 to 400 MHz region. To assure stability, the multiplication factors obtainable with the technique are limited to 10 or less. However, the technique is operationally simple in that relatively non-critical tuning adjustments are all that are required for operation over a wide frequency range. In view of the promise of the negative resistance technique, further investigation into the integration of negative resistance amplifiers directly into resonators should be pursued.

The performance of an active filter in a multiple signal environment is directly affected by the dynamic range and by the linearity of the transfer function within the limits of the dynamic range of the amplifiers in the filter. Negative feedback and power sharing techniques were effectively applied to broadband transistor amplifiers to achieve one watt output capabilities with second and third harmonic levels down at least 40 dB and 55 dB, respectively. As is generally true with any active device operating in a highly linear mode, the efficiency of the amplifiers is low, being in the neighborhood of 10 per cent.

The feasibility of suppressing closely spaced CW and AM interference through signal synthesis was shown with the breadboard model of the AM cancellation filter. Although the filter possesses certain limitations, it promises to fill a definite need for a suppression device in operational situations which do not permit the acquisition of a sample of the culprit signal directly from its source.

SECTION VI

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13. ABSTRACT

Several active filter techniques for the reduction of receiver interference in the 225 to 400 MHz range are described. Positive feedback Q multiplier techniques were extended to include (1) the use of multiple feedback loops to achieve a high order of stable multiplication in each stage and (2) the use of cascaded stages of Q-multiplied resonators to obtain improved skirt selectivity. Negative resistance Q multiplication was achieved over a wide frequency range through the development of a common collector transistor amplifier that exhibits stable negative resistance properties in the UHF region. The negative resistance amplifier was incorporated into a breadboard model of a tunable filter which employs both active and passive stages to produce a high Q response characteristic with high skirt selectivity over the entire band. An AM cancellation filter that achieves suppression of an unwanted signal by cancellation via a synthesized replica of the signal was developed. The breadboard model demonstrated a suppression capability of 30-35 dB for AM signals and about 50 dB for CW signals.

To enhance the capabilities and versatility of UHF active interference suppression filters, linearization techniques for broadband solid state amplifiers were investigated. The application of negative feedback and the use of the push-pull mode of parallel operation provided a significant reduction in harmonic generation while retaining good gain-band-width characteristics in amplifiers of one-watt power output capabilities.

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